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AIRLOADS:
A Program for Oscillatory Airloads on Blades of Turbosystems in Spatially Non-Uniform Inflow

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16. Abstract

AIRLOADS is a new computer program developed to determine the oscillatory airloads distribution imposed on the blades of turbosystems operating in spatially non-uniform inflow fields. The spatial non-uniformities are considered to be small deviations from a principally uniform inflow. The special case of turbosystems placed in uniform inflow fields with their axis of rotation misaligned at small angles with the inflow is also addressed.

Subsonic and supersonic two dimensional cascade unsteady aerodynamic theories are utilized to generate the applied airloads on the blade in a strip theory manner. Airloads for cascades with transonic relative inflows are linearly interpolated.

The program can be used as a stand-alone pre-processor to the general purpose finite element program NASTRAN in conducting modal flutter and aerodynamically forced vibration analyses of turbosystems. Both Case Control and Bulk Data Decks card-image files are generated for direct inclusion in NASTRAN response analysis.

All aspects of the AIRLOADS program are presented in this report.

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SUMMARY

AIRLOADS is a new computer program developed to determine the oscillatory airloads distribution imposed on the blades of turbosystems operating in spatially non-uniform inflow fields. The spatial non-uniformities are considered to be small deviations from a principally uniform inflow. The spatial non-uniformities are considered to be small deviations from a principally uniform inflow. The special case of turbosystems placed in uniform inflow fields with their axis of rotation misaligned at small angles with the inflow is also addressed.

Subsonic and supersonic two dimensional cascade unsteady aerodynamic theories are utilized to generate the applied airloads on the blade in a strip theory manner. Airloads for cascades with transonic relative inflows are linearly interpolated.

The program can be used as a stand-alone pre-processor to the general purpose finite element program NASTRAN in conducting modal flutter and aerodynamically forced vibration analyses of turbosystems. Both Case Control and Bulk Data Decks card-image files are generated for direct inclusion in NASTRAN response analysis.

All aspects of the AIRLOADS program are presented in this report.

AIRLOADS is operational on the CRAY 1-S computer system at NASA's Lewis Research Center.

The work was conducted under Contract NAS3-24387 from NASA LeRC, Cleveland, Ohio, with Mrs. Marsha Nall as the Project Monitor.

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TABLE OF CONTENTS

TABLE OF CONTENTS (continued)

LIST OF TABLES

LIST OF FIGURES

1. INTRODUCTION

AIRLOADS is a new computer program developed to determine the oscillatory airloads distribution imposed on the blades of turbosystems operating in spatially non-uniform steady inflow fields.

The airloads constitute loads that are,

1. derived from aerodynamic sources/causes,
2. externally applied to the turbosystem blades, and
3. not affected by the oscillatory motion of the blades.

The program also addresses the special case of turbosystems placed in uniform flow fields with their axis of rotation misaligned at small angles with the inflow.

For a turbosystem with swept or unswept blades, and with a rigid or flexible hub or disk, the airloads are computed at a given operating condition.

The blade is spanned by a number of non-intersecting chords as shown in Figure 1.1. Each chord is subdivided into a number of grid points from the leading edge to the trailing edge. The airloads are calculated at each of these grid points in terms of components directed along the displacement coordinate system axes at the grid point.

Subsonic and supersonic two-dimensional cascade unsteady

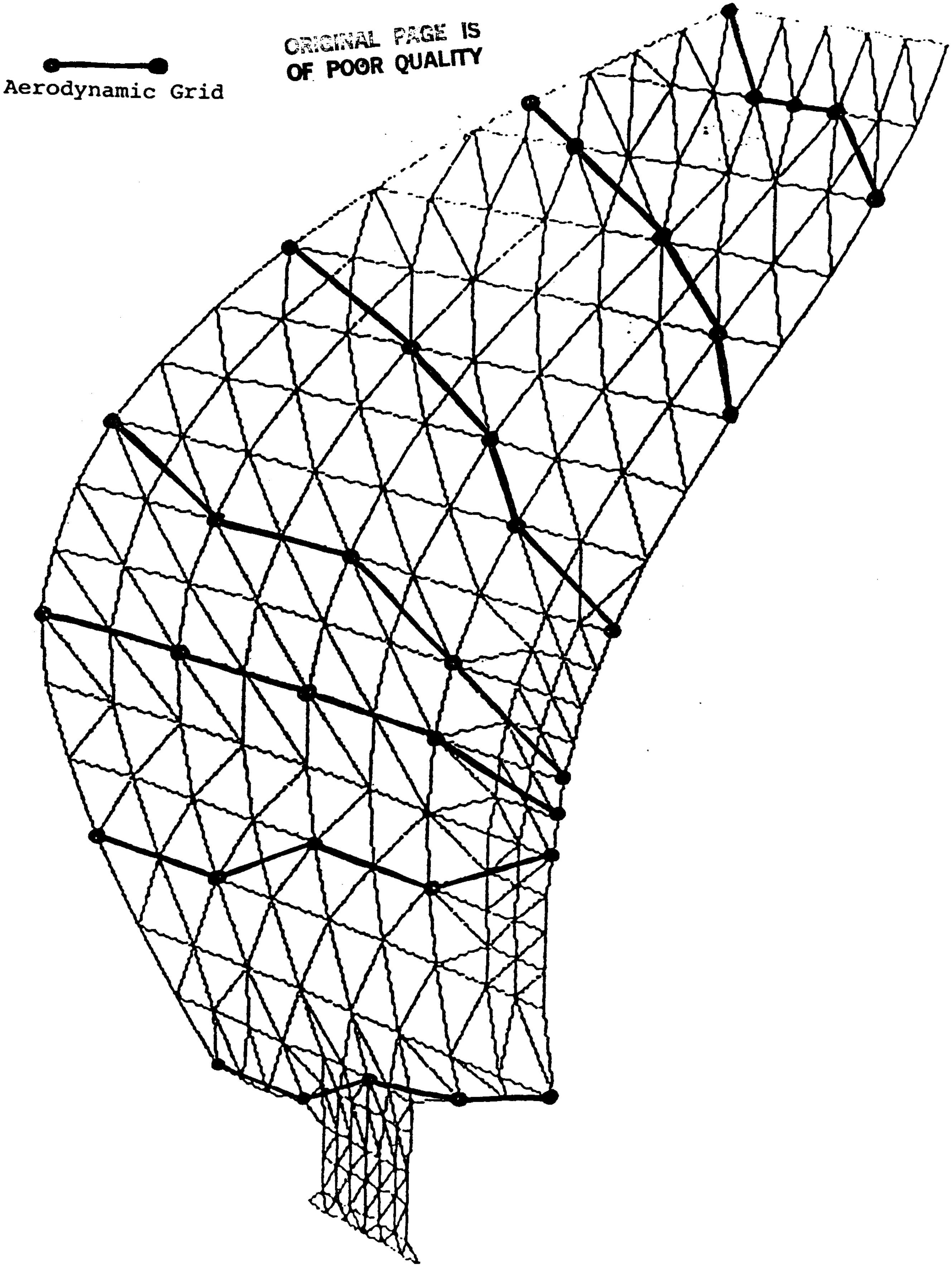


Figure 1.1 Sample Aerodynamic Grid for AIRLOADS Program

aerodynamic theories are utilized to generate the applied airloads on the blade. Airloads for cascades with transonic relative inflows are linearly interpolated or extrapolated.

The program can be used as a stand-alone pre-processor to the general purpose finite element program NASTRAN in conducting modal flutter and aerodynamically forced vibration analyses of turbosystems (Refs. 1 through 4).

Theoretical aspects of the program are presented in Section 2.

Program usage is discussed in Section 3.

Details of using the AIRLOADS program as a pre-processor to NASTRAN are given in Section 4.

Program structure is described in Section 5.

Sample examples illustrating the use of the AIRLOADS program are presented in Section 6.

2. THEORY

2.1 GENERAL

Theoretical aspects of generating the applied oscillatory aerodynamic loads on the blades of turbosystems due to oscillatory relative inflow is discussed in this section.

A rotating turbosystem placed in a spatially non-uniform inflow, or in a uniform inflow with its axis of rotation misaligned with inflow direction, experiences oscillatory relative inflow.

The resultant oscillatory airloads are computed by the use of subsonic and supersonic 2-d cascade unsteady aerodynamic theories (Refs. 5 and 6). Accordingly, the aerodynamic model of the blade comprises non-intersecting strips as shown in Figure 2.1. The swept blade of an advanced turboprop is shown as an example. The analytical development is equally applicable to unswept blades.

The computation of the oscillatory airloads is carried out in the following four steps:

1. For a given chord, sinusoidal gust amplitudes, frequencies, and other aerodynamic excitation parameters (Appendix A), are determined based on the relative inflow variations as the blades go through one revolution.

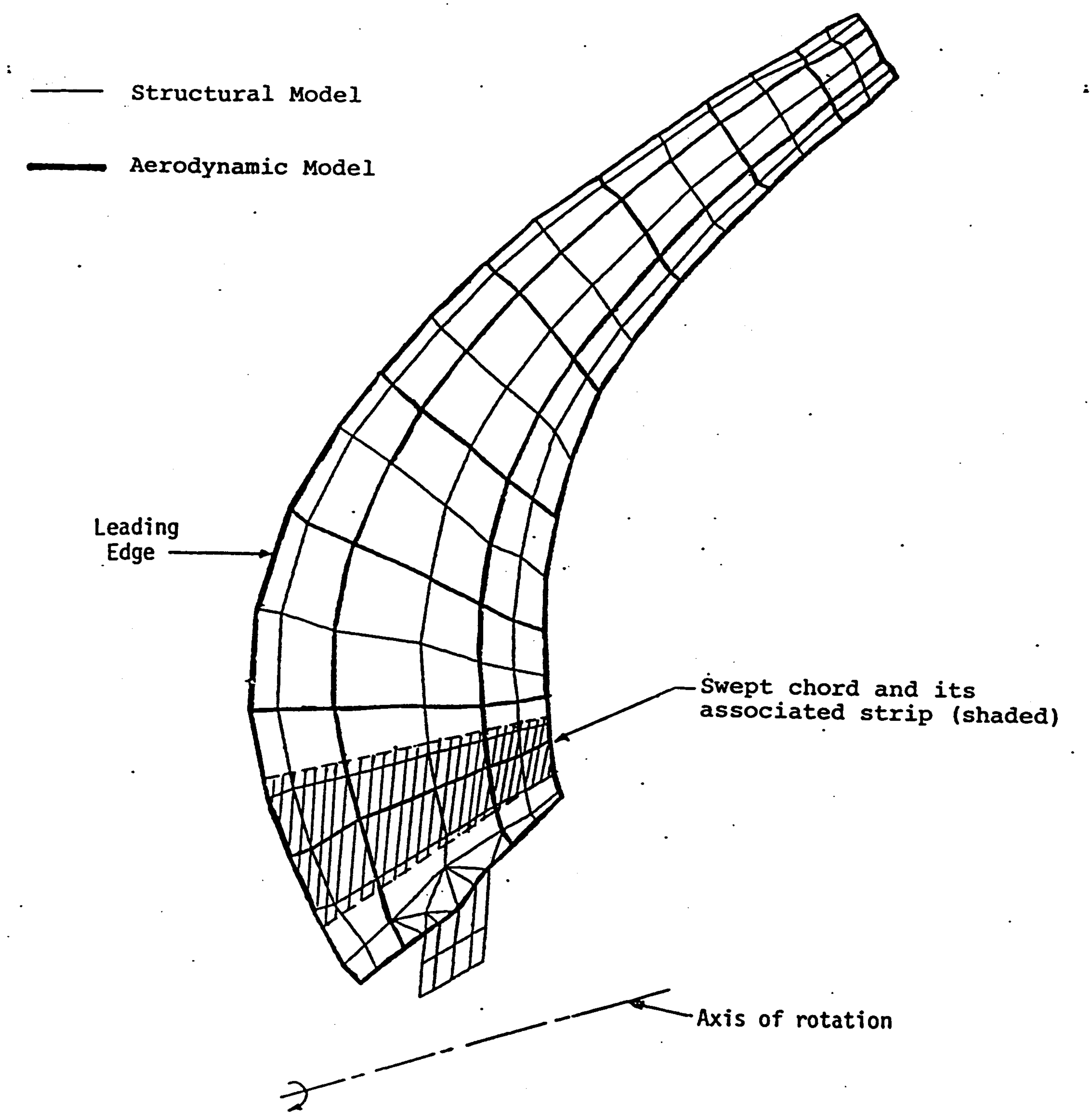


Figure 2.1 Swept Chord and Associated Strip for 2-D Cascade Theories (Ref. 3)

2. Subsonic or supersonic theory with appropriate gust inputs from step 1 is used to determine oscillatory pressure distributions on the chord.

3. The unsteady pressure distribution on the blade strip associated with the chord is transformed to loads at the finite element structural grid on the chord.

4. Steps 1 through 3 are repeated for all chords spanning the blade.

After establishing the relative inflow velocity to be either subsonic, transonic, or supersonic from step 1, step 2 is merely an application of the appropriate theory. In case of transonic relative inflow, the airloads for that chord are interpolated from adjacent non-transonic chords. Steps 1 and 3 are discussed further in the following sections.

2.2 GUST AMPLITUDES AND FREQUENCIES OF OSCILLATORY RELATIVE INFLOW

The problem of determining the amplitude and frequency contents of oscillatory relative inflow gusts can be accomplished in four steps:

1. At the leading edge point A of any chord ξ (Figure 2.2), the relative inflow velocity is determined as a function of time t (at discrete time instances) during one revolution of the turboprop rotating at a constant angular velocity Ω. (Definitions of all relevant coordinate systems are contained in Appendix B).

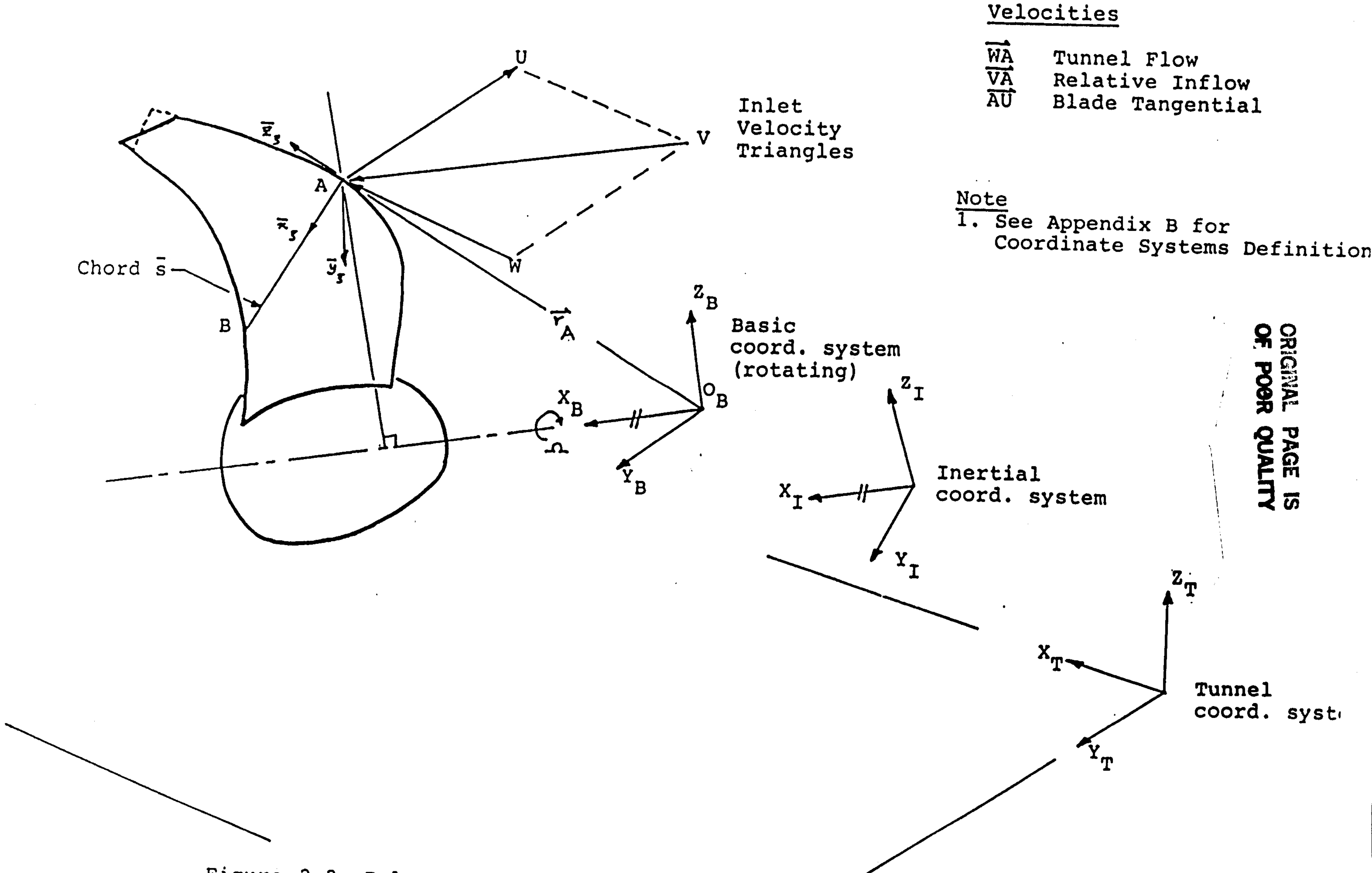


Figure 2.2 Inlet Velocity Triangles for Determining Oscillatory Relative Inflow

2. At each time step, the relative inflow velocity can be resolved into $\bar{x}_\xi$, $\bar{y}_\xi$, and $\bar{z}_\xi$ components of the local chord coordinate system (Figure 2.2).

- Component along $\bar{x}_\xi$ is the cascade relative inflow velocity. Component along $\bar{y}_\xi$ is the gust velocity. Component along $\bar{z}_\xi$ is the radial velocity, which is ignored in 2-d cascade aerodynamics.

3. A Fourier series decomposition in Ωt of

   a) the velocity component along $\bar{x}_\xi$ yields the cascade mean relative inflow velocity as the constant term of the Fourier series (along AB, Figure 2.2). This is used to determine the relative Mach number and select the appropriate aerodynamic theory.

   b) the velocity component along $\bar{y}_\xi$ yields the necessary sinusoidal gust amplitudes and frequencies which are subsequently input to appropriate oscillatory inflow aerodynamic theories.

4. Steps 1 through 3 are repeated for all chords spanning the blade to determine the oscillatory pressure distribution over the entire blade surface.

Referring to Figure 2.2, the relative inflow velocity at the leading edge point A on the chord ξ , expressed in the chord coordinate system, is

$$\{VA\}^{\bar{x}_{\bar{s}}\,\bar{y}_{\bar{s}}\,\bar{z}_{\bar{s}}} = [T_{\bar{s}}^{BL}][T^{IB}][T^{TI}]\{WA\}^{Tunnel} - [T_{\bar{s}}^{BL}]\begin{Bmatrix} \vec{\Omega}\times\vec{r}_A \cdot \hat{I}_B \\ \vec{\Omega}\times\vec{r}_A \cdot \hat{J}_B \\ \vec{\Omega}\times\vec{r}_A \cdot \hat{K}_B \end{Bmatrix}^{Basic} . \qquad (1)$$

In equation (1), the position vector is

$$\vec{r}_A = (O_BA)_{X_B}\,\hat{I}_B + (O_BA)_{Y_B}\,\hat{J}_B + (O_BA)_{Z_B}\,\hat{K}_B\,, \qquad (2)$$

and the coordinate transformations are

$$[T_{\bar{s}}^{BL}] = \begin{bmatrix} \beta_{11} & \beta_{12} & \beta_{13} \\ \beta_{21} & \beta_{22} & \beta_{23} \\ \beta_{31} & \beta_{32} & \beta_{33} \end{bmatrix}, \qquad (3)$$

$$[T^{TI}] = \begin{bmatrix} \tau_{11} & \tau_{12} & \tau_{13} \\ \tau_{21} & \tau_{22} & \tau_{23} \\ \tau_{31} & \tau_{32} & \tau_{33} \end{bmatrix}, \qquad (4)$$

and

$$[T^{IB}] = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\Omega t & \sin\Omega t \\ 0 & -\sin\Omega t & \cos\Omega t \end{bmatrix}. \qquad (5)$$

Selecting the angular velocity $\vec{\Omega}$ to be

$$\vec{\Omega} = \Omega\,\hat{I}_I = \Omega\,\hat{I}_B\,, \qquad (6)$$

equation (1) reduces to

$$\{VA\}^{\bar{x}_{\bar{s}}\bar{y}_{\bar{s}}\bar{z}_{\bar{s}}} = [G]\{WA\}^{Tunnel} - \Omega[T^{BL}_{\bar{s}}]\begin{Bmatrix} 0 \\ -(O_BA)_{z_B} \\ (O_BA)_{y_B} \end{Bmatrix}^{Basic}, \qquad (7)$$

where

$$[G] = [T^{BL}_{\bar{s}}][T^{IB}][T^{TI}] . \qquad (8)$$

For clarity of presentation, further development is separated into that for uniform and non-uniform inflows.

2.2.1 Uniform Inflow

In the uniform inflow case, the turbosystem axis of rotation is inclined at an angle γ with the uniform inflow velocity as shown in Figure B.2. The transformation from the tunnel to the inertial coordinate system (equation (4)) becomes

$$[T^{TI}] = \begin{bmatrix} \cos\gamma & 0 & -\sin\gamma \\ 0 & 1 & 0 \\ \sin\gamma & 0 & \cos\gamma \end{bmatrix}, \qquad (9)$$

with the uniform inflow velocity given by

$$\{WA\}^{Tunnel} = \begin{Bmatrix} (WA)_{X_T} \\ 0 \\ 0 \end{Bmatrix} . \qquad (10)$$

Substitution of equations (10), (9), (5) and (3) in equation (7) yields the constant (independent of Ωt) part of $(VA)_{\bar{x}}$, and the oscillating (function of Ωt) part of $(VA)_{\bar{y}}$ as

$$\text{con}\,(VA)_{\bar{x}} = \beta_{11}\cos\gamma\,(WA)_{X_T} - \Omega\left[-\beta_{12}(O_BA)_{Z_B} + \beta_{13}(O_BA)_{Y_B}\right], \qquad (11)$$

$$\text{osc}\,(VA)_{\bar{y}} = (WA)_{X_T}\sin\gamma\left[\beta_{22}\sin\Omega t + \beta_{23}\cos\Omega t\right]. \qquad (12)$$

The equivalent complex representation of equation (12) is

$$\text{osc}\,(VA)_{\bar{y}} = (WA)_{X_T}\sin\gamma\sqrt{\beta_{22}^2 + \beta_{23}^2}\;e^{i(\Omega t - \delta)}, \qquad (13)$$

with
$$\tan\delta = \beta_{22}/\beta_{23}. \qquad (14)$$

Equation (11) defines the cascade relative inflow velocity for the chord $\bar{s}$, whereas equation (13) describes the incoming gust velocity at the frequency Ω.

2.2.2 Non-Uniform Inflow

Equation (7), in its most general form, yields the expressions for the cascade relative inflow velocity and the gust velocity. The cascade inflow velocity is

$$(VA)_{\bar{z}} = g_{11}(WA)_{X_T} + g_{12}(WA)_{Y_T} + g_{13}(WA)_{Z_T} - \Omega\left[-\beta_{12}(O_BA)_{Z_B} + \beta_{13}(O_BA)_{Y_B}\right], \qquad (15)$$

where g_{ij}'s are the elements of the transformation G (equation

8), with

$$g_{11} = \beta_{11}\tau_{11} + \beta_{12}\left[\tau_{21}\cos\Omega t + \tau_{31}\sin\Omega t\right] + \beta_{13}\left[-\tau_{21}\sin\Omega t + \tau_{31}\cos\Omega t\right], \tag{16}$$

$$g_{12} = \beta_{11}\tau_{12} + \beta_{12}\left[\tau_{22}\cos\Omega t + \tau_{32}\sin\Omega t\right] + \beta_{13}\left[-\tau_{22}\sin\Omega t + \tau_{32}\cos\Omega t\right], \tag{17}$$

$$g_{13} = \beta_{11}\tau_{13} + \beta_{12}\left[\tau_{23}\cos\Omega t + \tau_{33}\sin\Omega t\right] + \beta_{13}\left[-\tau_{23}\sin\Omega t + \tau_{33}\cos\Omega t\right]. \tag{18}$$

The incoming gust velocity is

$$(VA)_{\bar{y}} = g_{21}(WA)_{x_T} + g_{22}(WA)_{y_T} + g_{23}(WA)_{z_T} - \Omega\left[-\beta_{22}(O_BA)_{z_B} + \beta_{23}(O_BA)_{y_B}\right], \tag{19}$$

where

$$g_{21} = \beta_{21}\tau_{11} + \beta_{22}\left[\tau_{21}\cos\Omega t + \tau_{31}\sin\Omega t\right] + \beta_{23}\left[-\tau_{21}\sin\Omega t + \tau_{31}\cos\Omega t\right], \tag{20}$$

$$g_{22} = \beta_{21}\tau_{12} + \beta_{22}\left[\tau_{22}\cos\Omega t + \tau_{32}\sin\Omega t\right] + \beta_{23}\left[-\tau_{22}\sin\Omega t + \tau_{32}\cos\Omega t\right], \tag{21}$$

$$g_{23} = \beta_{21}\tau_{13} + \beta_{22}\left[\tau_{23}\cos\Omega t + \tau_{33}\sin\Omega t\right] + \beta_{23}\left[-\tau_{23}\sin\Omega t + \tau_{33}\cos\Omega t\right]. \tag{22}$$

Both $(VA)_{\bar{x}}$ (equation (15)) and $(VA)_{\bar{y}}$ (equation (19)) are periodic functions of the azimuthal angle Ωt, with a maximum period of 2π as the blade completes one revolution in spatially non-uniform absolute inflow field. Each of these velocities can be expanded as finite Fourier series

$$f(\Omega t) = f_o + \sum_{p=1}^{P} \left[f_{pc} \cos \overline{p\Omega t} + f_{ps} \sin \overline{p\Omega t} \right]. \qquad (23)$$

The coefficients f_o, f_{pc}, and f_{ps} are determined by knowing f at M equally spaced intervals between 0 and 2π. The upper limit of harmonics, P, is given by

$$\left. \begin{aligned} P &= (M-1)/2 \quad , \quad M \text{ odd}, \\ &= M/2 \quad , \quad M \text{ even}. \end{aligned} \right\} \qquad (24)$$

In the non-uniform inflow case, the f_o component of $(VA)_{\bar{x}}$ is taken as the constant part of the cascade relative inflow velocity. For a selected harmonic p, the oscillating part of $(VA)_{\bar{y}}$ is written as

$$\text{osc}\,(VA)_{\bar{y}}\Big|_p = \sqrt{f_{pc}^2 + f_{ps}^2}\; e^{i(p\Omega t - \delta_p)}, \qquad (25)$$

with

$$\tan\delta_p = f_{ps} / f_{pc}. \qquad (26)$$

The excitation frequency correspondingly is $p\Omega$.

2.3 GRID POINT LOADS FROM OSCILLATORY PRESSURE DISTRIBUTION ALONG CHORD

The subsonic and supersonic aerodynamic routines compute the oscillatory pressure distribution at a number of points between the leading and trailing edges of a given chord. These points are generally distinct from the structural grid points at which the applied airloads are desired.

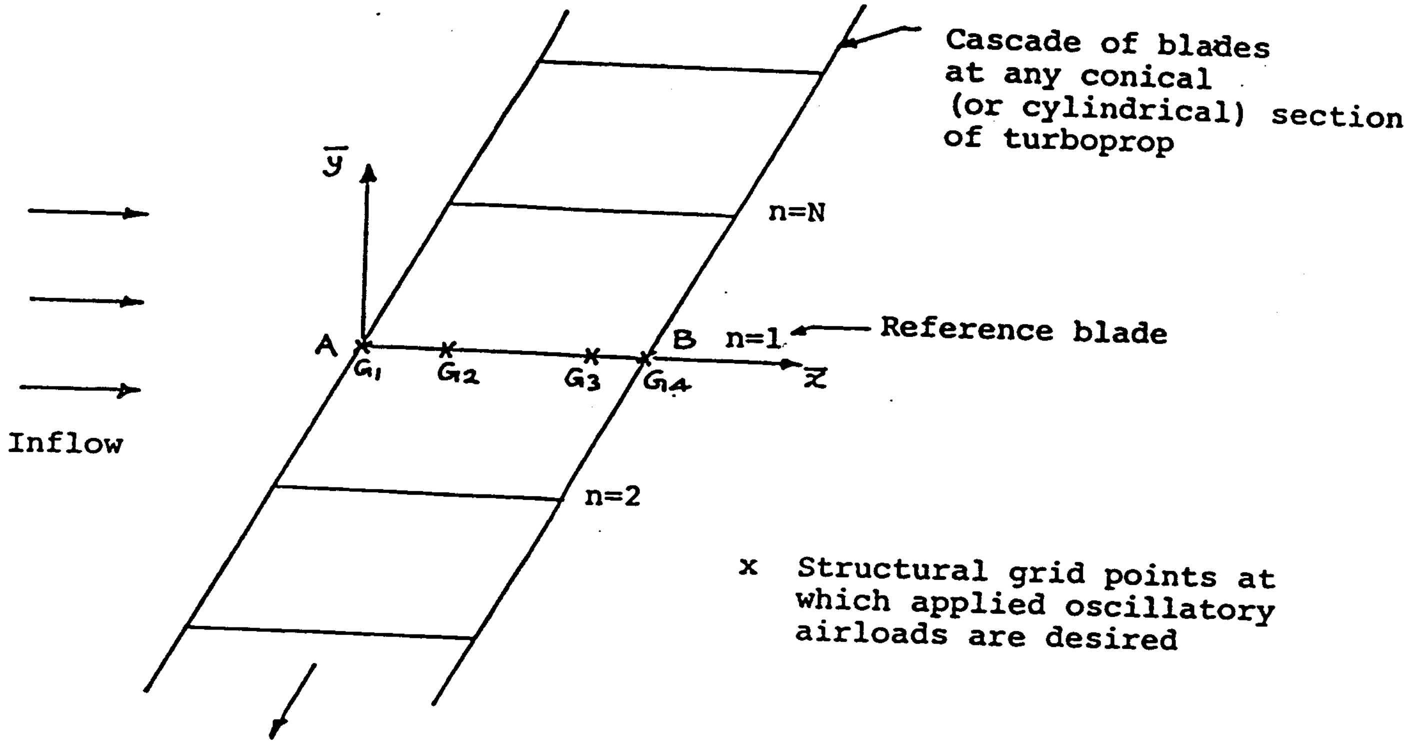
To obtain the loads at structural grid points, the chord is divided into a number of segments as shown in Figure 2.3. For each of the segments, the loads at its ends, directed along $+\bar{y}$, are calculated. As an example, for the $G_2 G_3$ segment,

$$P_{G_2} = \frac{1}{\Delta}\left[\int_{\bar{x}_{G_2}}^{\bar{x}_{G_3}} \Delta p(\bar{x})\cdot w(\bar{x})\cdot\overline{\bar{x}_{G_3}-\bar{x}}\; d\bar{x}\right], \text{ and} \tag{27}$$

$$P_{G_3} = \frac{1}{\Delta}\left[\int_{\bar{x}_{G_2}}^{\bar{x}_{G_3}} \Delta p(\bar{x})\cdot w(\bar{x})\cdot\overline{\bar{x}-\bar{x}_{G_2}}\; d\bar{x}\right], \tag{28}$$

where $\Delta = \bar{x}_{G_3} - \bar{x}_{G_2}$, and w is strip width associated with the given chord.

Furthermore, the load at grid point G_2, for instance, comprises the algebraic sum of those contributed by segments $G_1 G_2$ and $G_2 G_3$.



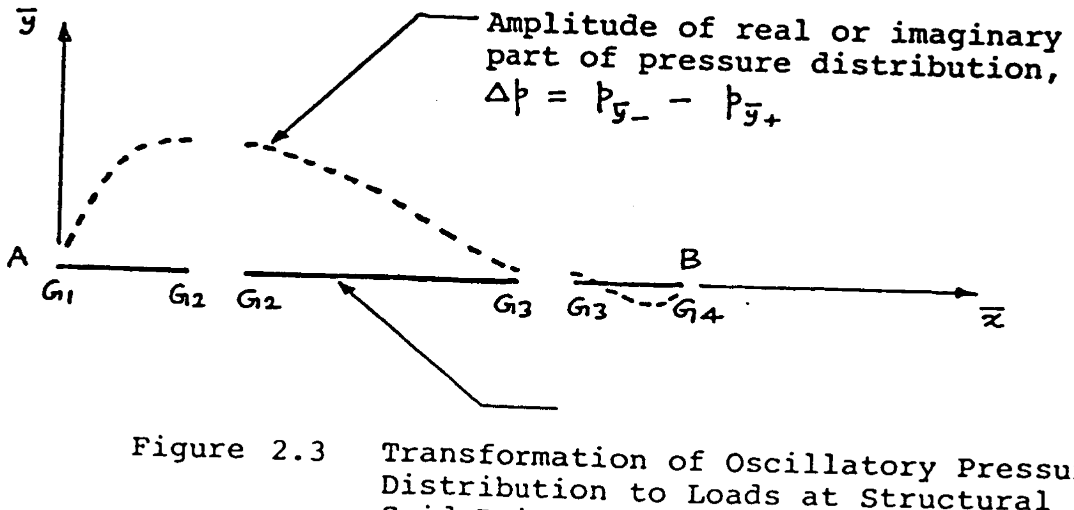


Figure 2.3 Transformation of Oscillatory Pressure Distribution to Loads at Structural Grid Points

Finally, the applied airload at any grid point g is obtained, in the displacement (global) coordinate system at that grid point, as

$$\{P_g\}^G = [T_g^{BG}][T_s^{BL}]^T\{P_g\}^L \quad , \tag{29}$$

where the grid point load, expressed in the local (chord) coordinate system, is

$$\{P_g\}^L = \begin{Bmatrix} 0 \\ P_g^{\bar{y}} \\ 0 \end{Bmatrix} . \tag{30}$$

Computation of $P_g^{\bar{y}}$ at grid point g is carried out using equations (27) and (28).

3. PROGRAM USAGE

3.1 GENERAL

The source of the AIRLOADS program on the CRAY 1-S computer system at NASA LeRC is called AIRSRCE . It is made available in the UPDATE Program Library format for easy and direct access to any subprogram(s).

The executable version of the AIRLOADS program on the CRAY is called AIRLOAD .

The program READs one user input data file from UNIT 5.

The program WRITEs one output file, containing all printed output, to UNIT 6.

If the program is run as a pre-processor to NASTRAN by requesting it (AIRLOAD) to output NASTRAN input data, the program also WRITEs,

1. NASTRAN Case Control Deck data to UNIT 7, and
2. NASTRAN Bulk Data Deck data to UNIT 8.

This information can be used to appropriately setup the installation-dependent JCL to use the AIRLOAD program.

Preparation of the user input data file is discussed in detail in the following subsections.

3.2 INPUT DATA

The entire input data for the AIRLOADS program consists of two parts:

1. Title Data, and
2. Problem Data .

The Title Data consists of the first two cards, and contains title and subtitle information.

The rest of the data from (and including) the third card on forms the Problem Data.

3.2.1 Title Data

The Title Data consisting of the TITLE and SUBTITLE cards is used to print the title and subtitle information on the first two lines of every page of the printed output.

The Title Data cards are free-field in format and are described in Section 3.3 .

3.2.2 Problem Data

The Problem Data contains all of the information required for the computation of the oscillatory airloads on the blades.

The format of the Problem Data cards is identical to that of the NASTRAN bulk data cards (Ref. 7). The 80 columns of each card are divided into 10 equal fields. The data within a field can be located anywhere in the field without any imbedded blanks. Real numbers can be specified in F, E, or D formats. When using E or D formats, the letters E or D must be included. These data cards offer the user the same convenience, flexibility and generality that is offered by the NASTRAN single-field bulk data cards. Double-field data is, however, permitted on CORD2C, CORD2R, CORD2S, GRDSET, and GRID Problem Data cards.

When using continuation cards, the tenth field of the parent card must be identical to the first field of the continuation card. The continuation cards must immediately follow the parent card. Comment cards ($), however, are allowed to intervene.

The Problem Data cards are described in Section 3.4 .

The first two cards in the Problem Data (i.e., the third and fourth cards in the entire data) must be the NLINES card and the FLOTYP card (in either order).

The rest of the Problem Data cards can be in any order, with the following three requirements:

1. GRDSET card, if used, must precede all GRID cards.

2. STREAML3 card must precede the GRID points identified on the card.

3. STREAML4 card, for a given streamline, must precede all STREAML5 cards (if used) for that streamline. The STREAML5 cards themselves, for that streamline, could be in any order.

It should be noted that during the processing of the input data,

1. if the number of STREAML3 cards encountered equals NLINES, and,

2. if all GRID point cards, collectively identified on all STREAML3 cards, have been encountered,

then the next GRID card, if present, is considered to mark the end of Problem Data. (Any subsequent cards are ignored.). Otherwise, input data processing continues until an end of file is encountered. This feature is designed for user convenience in that the user does not have to trim the (generally large) GRID data down to that referenced by STREAML3 cards.

The requirements for the individual Problem Data cards are explained under their descriptions in Section 3.4 .

A summary of all Input Data Cards for uniform and non-uniform inflow cases is presented in Table 3.1.

Table 3.1 Summary of All Input Data Cards

Input Data Card	Uniform Inflow	Non-Uniform Inflow	Default
TITLE	Required	Required	
SUBTITLE	Required	Required	
$	Optional	Optional	
CORD2C	Optional	Optional	
CORD2R	Optional	Optional	
CORD2S	Optional	Optional	
FLOTYP	Required	Required	
GRDSET	Optional	Optional	
GRID	Required	Required	
HUBTYP	Optional	Optional	Rigid
INCANG	Required	Not Used	
IREF	Optional	Optional	Tip streamline
MNMACH	Optional	Optional	1.01
MNPERREV	Not Used	Optional	
MXMACH	Optional	Optional	0.80
NASOUT	Optional	Optional	Yes
NLINES	Required	Required	
NSEGS	Required	Required	
PREVLIST	Not Used	Optional	
RPS	Required	Required	
SSOUND	Required	Required	
STREAML3	Required	Required	
STREAML4	Required	Required	
STREAML5	Not Used	Required	
TNLCID	Not Used	Optional	Inertial coord. system

3.3 TITLE DATA CARDS

Title Data Card | Title

<u>Description</u>: Defines a title that appears on the first line of each page of the printed output.

<u>Format and Example</u>:

Any legitimate characters in columns 1 through 80
THIS IS THE PROBLEM TITLE

<u>Remarks</u>:

1. The title card is a free-field card.
2. The very first card in the entire data is considered to be the title card.
3. This card is required.

Subtitle Data Card

Subtitle

Description: Defines a subtitle that appears on the second line of each page of the printed output.

Format and Example:

Any legitimate characters in columns 1 through 80
THIS IS THE PROBLEM SUBTITLE

Remarks:

1. The subtitle card is a free-field card.
2. The second card in the entire data is considered to be the subtitle card.
3. This card is required.

3.4 PROBLEM DATA CARDS

Problem Data Card <u>$</u> Comment

<u>Description</u>: Provides a means for the user to insert commentary material into the data.

<u>Format and Example</u>:

1	2	3	4	5	6	7	8	9	10
$ followed by any legitimate characters in columns 2 through 80									
$ THIS IS A COMMENT CARD									

<u>Remarks</u>:

1. The $ must be in column 1.
2. The comment card appears in the input data echo, but is otherwise ignored by the program.
3. The comment card may be inserted anywhere in the problem data.

Problem Data Card <u>CORD2C</u> Cylindrical Coordinate System Definition

Description: Defines a cylindrical coordinate system by reference to the coordinates of three points. The first point defines the origin. The second point defines the direction of the Z-axis. The third point lies in the plane of the azimuthal origin. The reference coordinate system, used to define this coordinate system, must be the basic coordinate system.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CORD2C	CID	RID	A1	A2	A3	B1	B2	B3	+XYZ
CORD2C	5	0	1.0	2.0	3.0	1.1	2.1	3.1	+CC
+XYZ	C1	C2	C3						
+CC	2.5	3.1	1.9						

Field	Contents
CID	Coordinate system identification number (Integer > 0)
RID	Identification number of the reference coordinate system. (Integer = 0 or blank, thereby always implying the basic coordinate system)
A1,A2,A3 B1,B2,B3 C1,C2,C3	Coordinates of three points defined in the basic coordinate system (Real)

Remarks:

1. As indicated, the value of RID (in field 3) must be an integer 0 or blank, thereby always implying the basic coordinate system. No non-zero integer is allowed in this field.

2. The CIDs on all CORD2C, CORD2R and CORD2S cards must be unique.

3. The three points (A1, A2, A3), (B1, B2, B3) and (C1, C2, C3) must be unique and non-collinear.

4. The total number of CORD2C, CORD2R and CORD2S cards used in the data may not exceed 10.

5. If single-field data is used, one continuation card must be used. If double-field data is used, two continuation cards must be used.

Problem Data Card **CORD2R** Rectangular Coordinate System Definition

Description: Defines a rectangular coordinate system by reference to the coordinates of three points. The first point defines the origin. The second point defines the direction of the Z-axis. The third point defines a vector which, with the Z-axis, defines the X-Z plane. The reference coordinate system,used to define this coordinate system, must be the basic coordinate system.

Format and Example:

1	2	3	4	5	6	7	8	9	10
CORD2R	CID	RID	A1	A2	A3	B1	B2	B3	+XYZ
CORD2R	5	0	1.0	2.0	3.0	1.1	2.1	3.1	+CC
+XYZ	C1	C2	C3						
+CC	2.5	3.1	1.9						

Field	Contents
CID	Coordinate system identification number (Integer > 0)
RID	Identification number of the reference coordinate system. (Integer = 0 or blank, thereby always implying the basic coordinate system)
A1,A2,A3 B1,B2,B3 C1,C2,C3	Coordinates of three points defined in the basic coordinate system (Real)

Remarks:

1. As indicated, the value of RID (in field 3) must be an integer 0 or blank, thereby always implying the basic coordinate system. No non-zero integer is allowed in this field.

2. The CIDs on all CORD2C, CORD2R and CORD2S cards must be unique.

3. The three points (A1, A2, A3), (B1, B2, B3) and (C1, C2, C3) must be unique and non-collinear.

4. The total number of CORD2C, CORD2R and CORD2S cards used in the data may not exceed 10.

5. If single-field data is used, one continuation card must be used. If double-field data is used, two continuation cards must be used.

Problem Data Card <u>CORD2S</u> Spherical Coordinate System Definition

<u>Description</u>: Defines a spherical coordinate system by reference to the coordinates of three points. The first point defines the origin. The second point defines the direction of the Z-axis. The third point lies in the plane of the azimuthal origin. The reference coordinate system, used to define this coordinate system, must be the basic coordinate system.

<u>Format and Example</u>:

1	2	3	4	5	6	7	8	9	10
CORD2S	CID	RID	A1	A2	A3	B1	B2	B3	+XYZ
CORD2S	5	0	1.0	2.0	3.0	1.1	2.1	3.1	+CC
+XYZ	C1	C2	C3						
+CC	2.5	3.1	1.9						

<u>Field</u>	<u>Contents</u>
CID	Coordinate system identification number (Integer > 0)
RID	Identification number of the reference coordinate system. (Integer = 0 or blank, thereby always implying the basic coordinate system)
A1,A2,A3 B1,B2,B3 C1,C2,C3	Coordinates of three points defined in the basic coordinate system (Real)

<u>Remarks</u>:

1. As indicated, the value of RID (in field 3) must be an integer 0 or blank, thereby always implying the basic coordinate system. No non-zero integer is allowed in this field.
2. The CIDs on all CORD2C, CORD2R and CORD2S cards must be unique.
3. The three points (A1, A2, A3), (B1, B2, B3) and (C1, C2, C3) must be unique and non-collinear.

4. The total number of CORD2C, CORD2R and CORD2S cards used in the data may not exceed 10.

5. If single-field data is used, one continuation card must be used. If double-field data is used, two continuation cards must be used.

Problem Data Card FLOTYP   Flow Type Definition

Description: Defines the type of absolute inflow as uniform or non-uniform, and, if uniform, also specifies the inflow velocity.

Format and Example:

1	2	3	4	5	6	7	8	9	10
FLOTYP	FLTYPE	INVEL							
FLOTYP	UNIFORM	5500.							

Field	Contents
FLTYPE	Type of absolute inflow (BCD). Must be either UNIFORM to indicate uniform flow, or NUNIFORM to indicate non-uniform flow.
INVEL	Inflow velocity if FLTYPE is UNIFORM (Real). Ignored if FLTYPE is NUNIFORM.

Remarks:

1. The FLOTYP card is required; only one such card is allowed.
2. Like the NLINES card (see description), the FLOTYP card should be the first or the second card immediately after the title and subtitle cards.

Problem Data Card <u>GRDSET</u> Grid Point Default

<u>Description:</u> Defines default options for fields 3 and 7 of all GRID cards.

<u>Format and Example:</u>

1	2	3	4	5	6	7	8	9	10
GRDSET		CP				CD	PS		
GRDSET		4				7	456		

Field	Contents
CP	Identification number of the default coordinate system in which the locations of the grid points are defined (Integer $\geqslant$ 0)
CD	Identification number of the default coordinate system in which the displacements at grid points are defined (Integer $\geqslant$ 0)
PS	Ignored in the AIRLOADS program (but used in NASTRAN)

<u>Remarks:</u>

1. The contents of fields 3 and 7 of this card are assumed for the corresponding fields of any GRID card whose fields 3 and/or 7 are blank.
2. Only one GRDSET card may appear in the data. If used, it must precede all GRID cards in the data.
3. If double-field data is used, the continuation card must be used.

Problem Data Card GRID Grid Point Definition,

Description: Defines the location of a grid point and the coordinate system for its displacements.

Format and Example:

1	2	3	4	5	6	7	8	9	10
GRID	GID	CP	XX	YY	ZZ	CD	PS		
GRID	10	3	1.0	2.5	5.3	5	345		

Field	Contents
GID	Grid point identification number (Integer > 0)
CP	Identification number of the coordinate system in which the location of the grid point is defined (Integer ≥ 0 or blank)
XX,YY,ZZ	Location coordinates of the grid point in coordinate system CP (Real, see Figure 3.1)
CD	Identification number of the coordinate system in which the displacements of the grid point are defined (Integer ≥ 0 or blank)
PS	Ignored in the AIRLOADS program (but used in NASTRAN)

Remarks:

1. If a GRDSET card is present, then it must precede all GRID cards.
2. This card is processed only if the grid point identification number has been defined earlier, in the data deck, on a STREAML3 card.
3. All grid point identification numbers must be unique.
4. If the fields 3 and/or 7 are blank, then the default values specified on the GRDSET card (if any) are used.
5. GRID cards are required in the data.

6. If double-field data is used, the continuation card must be used.

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Notes
1. XX, YY, ZZ are location coordinates of grid point
2. T1, T2, T3 are translational displacement directions at grid point

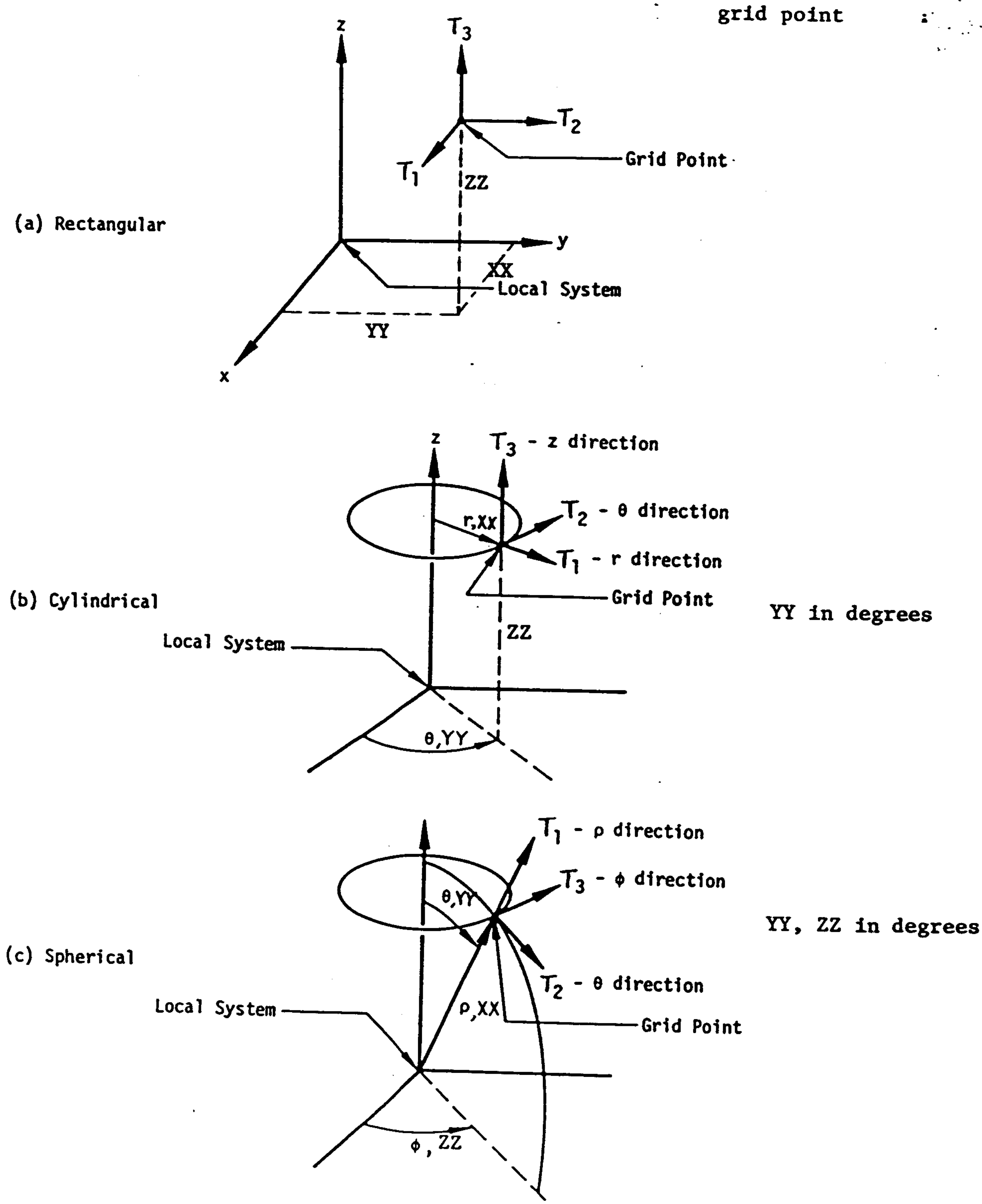


Figure 3.1 Grid Point Location and Displacements (Ref. 7)

Problem Data Card **HUBTYP** Hub/Disk Type Definition

Description: Defines the type of hub/disk, as rigid or flexible.

Format and Example:

1	2	3	4	5	6	7	8	9	10
HUBTYP	HUBTYPE								
HUBTYP	FLEX								

Field **Contents**

HUBTYPE Hub/Disk type (BCD). Must be either RIGID to indicate a rigid hub/disk, or FLEX to indicate a flexible hub/disk. The default is RIGID.

Remarks: 1. Only one HUBTYP card may be used in the data.

Problem Data Card <u>INCANG</u> Rotational Axis Inclination Angle Definition

Description: Defines the inclination angle of the axis of rotation of the turbosystem with the UNIFORM absolute inflow.

Format and Example:

1	2	3	4	5	6	7	8	9	10
INCANG	ANGLE								
INCANG	10.0								

Field	Contents
ANGLE	Inclination angle (in degrees) of the rotational axis (Real, see Figure B.2, Appendix B)

Remarks: 1. The INCANG card is required only if UNIFORM is specified on FLOTYP card; only one such card is allowed.

Problem Data Card <u>IREF</u> Reference Streamline Identification

<u>Description:</u> Defines the identification number of the reference streamline.

<u>Format and Example:</u>

1	2	3	4	5	6	7	8	9	10
IREF	REFID								
IREF	30								

<u>Field</u>	<u>Contents</u>
REFID	Identification number of the reference streamline (Integer > 0). The default is the highest streamline identification number defined on STREAML3/STREAML4 cards.

<u>Remarks:</u> 1. Only one IREF card may be used in the data.

Problem Data Card MNMACH   Supersonic Flow Limit

Description: Defines the lower Mach number limit for supersonic relative flow.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MNMACH	LWRLMT								
MNMACH	1.1								

Field	Contents
LWRLMT	Lower Mach number limit at and above which supersonic relative flow is assumed. (Real > 1.0). The default is 1.01.

Remarks: 1. Only one MNMACH card may be used in the data.

Problem Data Card **MNPERREV** Excitation Frequencies Definition

Description: Defines the lowest of a series of eight consecutive excitation frequencies, as integer multiple of turbosystem rotational speed.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MNPERREV	NN								
MNPERREV	3								

Field	Contents
NN	Defines NN-per-rev as the lowest excitation frequency of a series of eight consecutive excitation frequencies, in non-uniform inflow case. Oscillatory airloads are determined at these frequencies. (Integer > 0)

Remarks:

1. The MNPERREV card is ignored if the flow type is defined as UNIFORM on the FLOTYP card.
2. See PREVLIST card for selectively picking excitation frequencies.
3. Only one MNPERREV card may be used in the data. This card is ignored if PREVLIST card is also present.
4. In non-uniform inflow case, if BOTH MNPERREV and PREVLIST cards are absent, only ONE one-per-rev excitation frequency is assumed.

Problem Data Card **MXMACH** Subsonic Flow Limit

Description: Defines the upper Mach number limit for subsonic relative flow.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MXMACH	UPRLMT								
MXMACH	0.9								

Field	Contents
UPRLMT	Upper Mach number limit at and below which subsonic relative flow is assumed. ($0.0 < \text{Real} \leq 1.0$). The default is 0.80 .

Remarks: 1. Only one MXMACH card may be used in the data.

Problem Data Card NASOUT

Request for Pre-Processed NASTRAN Input

Description: Specifies whether output data compatible with NASTRAN input requirements is generated or not.

Format and Example:

1	2	3	4	5	6	7	8	9	10
NASOUT	NASFLAG								
NASOUT	NO								

Field	Contents
NASFLAG	Flag to indicate if output compatible with NASTRAN input requirements is to be generated or not. Must be either YES or NO. The default is YES.

Remarks: 1. Only one NASOUT card may be used in the data.

Problem Data Card **NLINES** Streamlines Specification

Description: Specifies the number of streamlines used in the analysis.

Format and Example:

1	2	3	4	5	6	7	8	9	10
NLINES	N								
NLINES	40								

Field **Contents**

N Number of streamlines ($2 \leq$ Integer ≤ 50)

Remarks:

1. The NLINES card is required; only one such card is allowed.
2. Like the FLOTYP card (see description), the NLINES card should be the first or the second card immediately after the title and subtitle cards.

Problem Data Card <u>NSEGS</u> Blade Segment Definition

Description: Defines the number of blades on the turbosystem.

Format and Example:

1	2	3	4	5	6	7	8	9	10
NSEGS	NBLADES								
NSEGS	4								

Field	Contents
NBLADES	Number of blade segments (Integer > 1)

Remarks: 1. The NSEGS card is required; only one such card is allowed.

Problem Data Card **PREVLIST** Excitation Frequencies List

Description: In non-uniform inflow case, defines a list of excitation frequencies at which the oscillatory airloads are determined.

Format and Example:

1	2	3	4	5	6	7	8	9	10
PREVLIST	N1	N2	N3	N4	N5	N6	N7	N8	
PREVLIST	1	3	6	7					

Field	Contents
Ni	Ni-per-rev are the excitation frequencies. (Integer; $0 < Ni < N(i+1)$)

Remarks:

1. The PREVLIST card is ignored if the flow type is defined as UNIFORM on the FLOTYP card.
2. See MNPERREV card for alternative method.
3. Only one PREVLIST card may be used in the data. If this card is present, MNPERREV card is ignored.
4. In non-uniform inflow case, if BOTH PREVLIST and MNPERREV cards are absent, only ONE one-per-rev excitation frequency is assumed.

Problem Data Card <u>RPS</u> Rotational Speed Definition

<u>Description:</u> Defines the rotational speed of the turbosystem.

<u>Format and Example:</u>

1	2	3	4	5	6	7	8	9	10
RPS	SPEED								
RPS	200.0								

<u>Field</u>	<u>Contents</u>
SPEED	Rotational speed in revolutions per unit time (Real $\neq$ 0.0)

<u>Remarks:</u> 1. The RPS card is required; only one such card is allowed.

Problem Data Card **SSOUND** Speed of Sound Definition

Description: Defines the speed of sound in free stream.

Format and Example:

1	2	3	4	5	6	7	8	9	10
SSOUND	SPEED								
SSOUND	1.3E4								

Field	Contents
SPEED	Speed of sound (Real $>$ 0.0)

Remarks: 1. The SSOUND card is required; only one such card is allowed.

Problem Data Card <u>STREAML3</u> Aerodynamic Grid Definition on a Streamline

<u>Description</u>: Defines the grid points on a specified streamline, as part of the aerodynamic grid. Oscillatory airloads are computed at these grid points.

<u>Format and Example</u>:

1	2	3	4	5	6	7	8	9	10
STREAML3	SLID	G1	G2	G3	G4	G5	G6	G7	G8
STREAML3	100	12	15	10	44	33			

<u>Field</u>	<u>Contents</u>
SLID	Streamline identification number (Integer > 0)
Gi	Grid point identification numbers (Integer > 0)

<u>Remarks</u>:

1. At least two grid points must be specified, and a maximum of eight grid points can be specified.
2. The first grid point specified corresponds to to the leading edge and the last grid point specified corresponds to the trailing edge.
3. All grid point identification numbers must be unique and must be subsequently defined on GRID cards.
4. The number of STREAML3 cards in the data must equal the number of streamlines specified on the NLINES card (see description), and must be the same as the number of STREAML4 cards in the data.
5. The streamline identification numbers specified on STREAML3 cards must be the same as those specified on STREAML4 cards.
6. The number of grid points on STREAML3 cards can vary from streamline to streamline.
7. STREAML3 cards are required in the data.

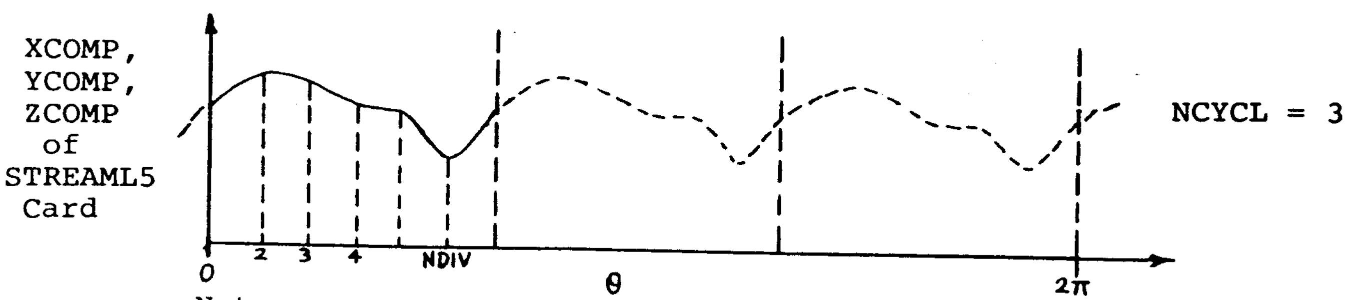
Problem Data Card **STREAML4** **Inflow Data Definition**

Description: Defines inflow data characteristics.

Format and Example:

1	2	3	4	5	6	7	8	9	10
STREAML4	SLID	FLDEN	NCYCL	NDIV					
STREAML4	150	1.2D-9	3	6					

Field	Contents
SLID	Streamline identification number (Integer > 0)
FLDEN	Inflow density (Real > 0.0)
NCYCL	This is ignored in uniform inflow case. For non-uniform inflow, NCYCL represents the number of cycles of variation of the absolute inflow velocity as seen at the leading edge point of this streamline, when the modelled blade completes one revolution (see sketch below). (Integer $\geq$ 1)
NDIV	This is ignored in uniform inflow case. For non-uniform inflow, NDIV specifies the number of equally spaced intervals in one cycle of absolute inflow variation (see sketch below) . (Integer; $3 \leq$ NDIV ≤ 30)



Notes

1. θ is the circumferential angle traversed by the leading edge point of streamline,as modelled blade rotates through one complete revolution.
2. For uniformity of reference for all streamlines, $\theta=0$ is taken when time t =0, i.e., when the basic and the inertial coordinate systems are parallel. See Appendix B.

Remarks:

1. The number of STREAML4 cards in the data must equal the number of streamlines specified on the NLINES card (see description) and must be the same as the number of STREAML3 cards in the data.
2. The streamline identification numbers specified on STREAML4 cards must be the same as those specified on STREAML3 cards.
3. STREAML4 cards are required in the data.
4. In uniform inflow case, NCYCL and NDIV are not required.

Problem Data Card **STREAML5** Non-Uniform Inflow Variation Definition

Description: Defines the absolute inflow velocity components for a streamline at equally-spaced NDIV circumferential locations, in non-uniform inflow case (see sketch for STREAML4 card).

Format and Example:

1	2	3	4	5	6	7	8	9	10
STREAML5	SLID	DIVNO	XCOMP	YCOMP	ZCOMP				
STREAML5	180	4	1.0E4	836.0	9.E03				

Field	Contents
SLID	Streamline identification number (Integer > 0)
DIVNO	Equally-spaced division number (Integer > 0)
XCOMP, YCOMP, ZCOMP	Components of absolute inflow velocity at the leading edge point of this streamline, expressed in the coordinate system identified on TNLCID card (Real)

Remarks:

1. STREAML5 cards are ignored if the flow type is specified as uniform on the FLOTYP card.
2. STREAML5 cards are required if the flow type is specified as non-uniform on the FLOTYP card.
3. The streamline identification number must have appeared earlier on a STREAML4 card.
4. The division number must not exceed the number of divisions specified on the STREAML4 card for the given streamline identification number.
5. The number of STREAML5 cards for a given streamline identification number must equal the number of divisions specified on the STREAML4 card for that streamline.

Problem Data Card TNLCID — Free Stream Coordinate System Definition in Non-Uniform Inflow Case

Description: Identifies the coordinate system in which the absolute inflow velocity is known.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TNLCID	TCID								
TNLCID	15								

Field	Contents
TCID	Identification number of coordinate system (Integer $>$ 0)

Remarks:

1. The TNLCID card is ignored if the flow type is defined as uniform on the FLOTYP card.
2. The TCID coordinate system must be fixed in space and time; must be defined in the inertial coordinate system instead of the basic coordinate system; must be a rectangular coordinate system.
3. If TCID is 0, or if TNLCID card is not included in non-uniform inflow case, TCID is assumed to coincide with the inertial coordinate system.
4. Only one TNLCID card may be used in the data.

4. AIRLOADS AS PRE-PROCESSOR TO NASTRAN

4.1 GENERAL

The AIRLOADS program can be used as a pre-processor to NASTRAN in conducting modal forced vibration analysis of turbosystems subjected to excitation from aerodynamic sources (Refs. 3 and 4).

As discussed in detail in these references, the bladed disks of turbosystems are treated as tuned cyclic structures rotating about their axis of symmetry. Circumferential harmonic-dependent normal modes of such tuned rotating cyclic structures are used in formulating and solving the dynamic response problem in the frequency domain.

Accordingly, the AIRLOADS program generates the applied oscillatory airloads in terms of the circumferential harmonic-dependent cosine and sine components, $\bar{P}^{kc}$ and $\bar{P}^{ks}$ (see Ref. 3), in the frequency domain.

The Problem Data card NASOUT is used to activate the pre-processing capabilities of AIRLOADS (Section 3.4).

Two output files are created, in addition to the printed output, when YES is specified on the NASOUT card. These files can be directly used, without any modifications, in NASTRAN input data decks. The files can be physically included at appropriate locations in NASTRAN input, or can be included via the READFILE capability of NASTRAN.

To avoid any ambiguity between AIRLOADS and NASTRAN runs, the contents of the output files completely reflect all structural and flow conditions specified at input to the AIRLOADS program. Hence, any changes, if planned, to the output files must be carefully examined by the user before proceeding with subsequent NASTRAN runs.

The output file written to UNIT 7 contains NASTRAN Case Control Deck information. This includes the definition of SUBCASES with appropriate DLOAD cards for the applied airloads. FREQUENCY card, referencing the FREQ bulk data card, is also output. Subcase definition is further discussed in Section 4.2 . Descriptions of DLOAD and FREQUENCY Case Control Deck cards, taken from Ref. 7, are included in Section 4.5 .

The output file written to UNIT 8 contains NASTRAN Bulk Data Deck information. Output cards include AERO , DAREA , DPHASE , FREQ , MKAERO2 , RLOAD1 , STREAML1 , STREAML2 , and TABLED1 bulk data cards. The PARAMeters output are BOV , CYCIO , IREF , KMAX , KMIN , MAXMACH , MINMACH , NSEGS , Q , and RPS . The parameters are described in Section 4.3 . Descriptions of the other bulk data cards, taken from Refs. 7 and 4, are presented in Section 4.6 . Additional remarks on some of these cards are given in Section 4.4 .

The bulk data cards AERO, STREAML1, and STREAML2 are also useful in conducting modal flutter analysis of the turbosystem (Refs. 1 and 2) .

4.2 SUBCASE DEFINITIONS IN CASE CONTROL DECK

The PARAMeter KMAX ($\geqslant 0$, $\leqslant$ NSEGS/2 for even NSEGS, $\leqslant$ (NSEGS-1)/2 for odd NSEGS) determines the number, order and meaning of subcases as follows:

The number of subcases is equal to FKMAX, where

FKMAX = 1, if KMAX = 0,
= 1 + 2*KMAX, if 0 KMAX (NSEGS-1)/2, NSEGS odd,
= 1 + 2*KMAX, if 0 KMAX (NSEGS-2)/2 NSEGS even,
and
= NSEGS, if KMAX = NSEGS/2, NSEGS even.

SUBCASE 1 ('k' = 0)
SUBCASE 2 ('k' = 1c)
SUBCASE 3 ('k' = 1s)
SUBCASE 4 ('k' = 2c)
SUBCASE 5 ('k' = 2s)
.
.
.

SUBCASE FKMAX ('k' = KMAXs).

In the event that NSEGS is even and KMAX = NSEGS/2, Subcase FKMAX will represent 'k' = KMAXc as KMAXs does not exist.

Circumferential harmonic components of applied airloads are specified under the appropriate subcases.

4.3 PARAMETER DEFINITIONS IN BULK DATA DECK

1. NSEGS - The integer value of this parameter is the number of identical segments in the structural model.

2. CYCIO - The integer value of this parameter specifies the form of the input and output data. A value of +1 is used to specify physical segment representation, and a value of -1 for cyclic transform representation. The value of CYCIO is set to -1.

3. KMAX - The integer value of this parameter specifies the maximum value of the harmonic index, and is used in subcase definition.

4. KMIN - The integer value of this parameter specifies the minimum value of the harmonic index.

   In NASTRAN runs, if KMIN (≥ 0, default = 0) equals KMAX, then Parameter KINDEX is internally defined equal to KMIN and KMAX. User supplied KINDEX is ignored.

   In NASTRAN runs, if KMIN differs from KMAX, then KINDEX (KMIN $\leq$ KINDEX $\leq$ KMAX) must be specified.

5. RPS - The real value of this parameter defines the rotational speed of the structure in revolutions per unit time.

6. MINMACH - This is the minimum Mach number at and above which the supersonic unsteady cascade theory is valid.

7. MAXMACH - This is the maximum Mach number at and below which the subsonic unsteady cascade theory is valid.

8. IREF - This defines the reference streamline number.

9. Q - Based on the reference streamline density and velocity on STREAML2 card, this parameter specifies the inflow dynamic pressure at the operating condition.

10. BOV - This parameter represents the ratio of the semichord to the velocity on the reference STREAML2 card.

4.4 REMARKS ON SOME BULK DATA CARDS

AERO. The variables on this card represent the conditions for the entire blade/turbosystem as a whole. The values of these variables on the reference streamline are assigned to also represent those for the entire blade/turbosystem.

The reference streamline is picked by the user (PARAM IREF), and defaults to tip streamline otherwise.

STREAML2. This card defines the unsteady aerodynamic data for a given streamline.

Figure 4.1 illustrates some of the definitions pertinent to swept blade aerodynamics.

MKAERO2. The reduced frequency on these cards is based on the

NOTES

1. AI is parallel to axis of rotation, and in general, is NOT in WAU plane
2. $\overrightarrow{VA}$ is always in WAU plane
3. Point D is in IAU plane
4. Λ is positive sweep angle
5. λ is positive stagger angle

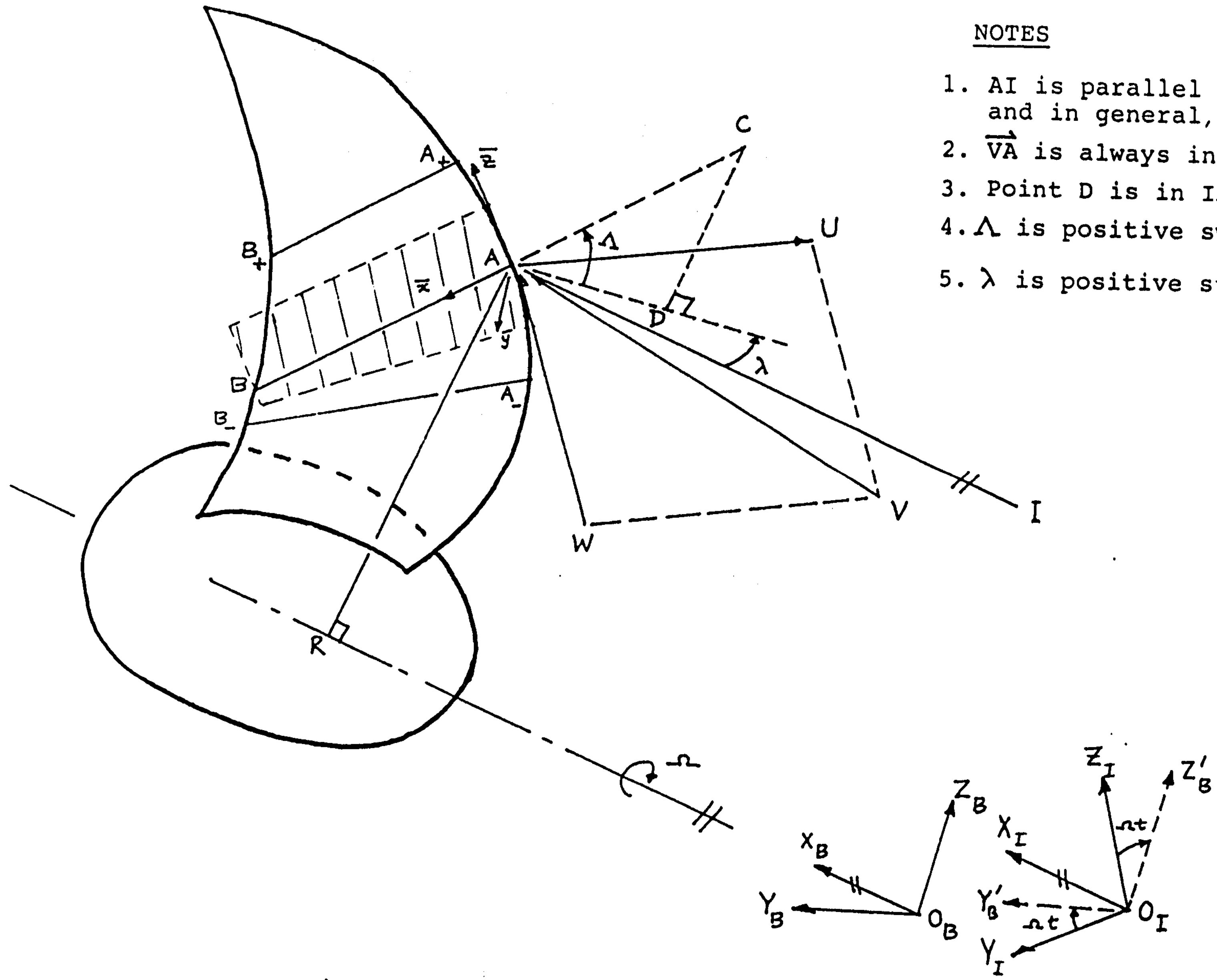
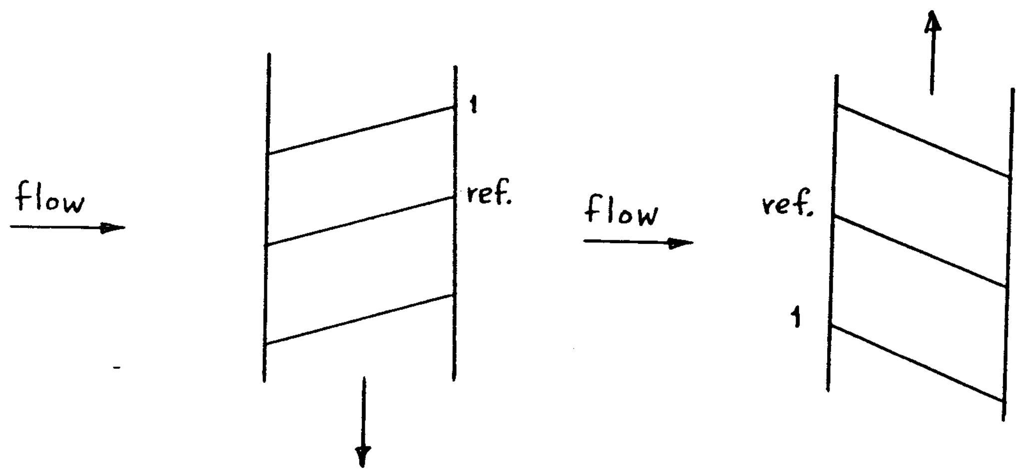


Figure 4.1 Some Definitions for Swept Blade Aerodynamics (STREAML2 Bulk Data Card)

semichord and velocity on STREAML2 card for reference streamline.

Positive inter-blade phase angle is taken when, in the following sketch, blade 1 <u>LEADS</u> the reference blade.



4.5 CASE CONTROL DECK CARDS (FROM REF. 7)

Case Control Data Card DLØAD - Dynamic Load Set Selection.

Description: Selects the dynamic load to be applied in a Transient or Frequency Response problem.

Format and Example(s):

DLØAD = n

DLØAD = 73

Option	Meaning
n	Set identification of a DLØAD, RLØAD1, RLØAD2, TLØAD1, or TLØAD2 card (Integer > 0).

Remarks:

1. The above loads will not be used by NASTRAN unless selected in Case Control.
2. RLØAD1 and RLØAD2 may only be selected in a Frequency Response problem.
3. TLØAD1 and TLØAD2 may only be selected in a Transient Response problem.
4. Either RLØAD or TLØAD (but not both) may be selected in an Aeroelastic Response problem. If RLØAD is selected, a Frequency Response is calculated. If TLØAD is selected, then Transient Response is computed by Fourier Transform.

Case Control Data Card FREQUENCY - Frequency Set Selection

Description: Selects the set of frequencies to be solved in Frequency Response problems.

Format and Example(s):

FREQUENCY = n
FREQUENCY = 17

Option	Meaning
n	Set identification of a FREQ, FREQ1 or FREQ2 type card (Integer > 0).

Remarks:

1. The FREQ, FREQ1 or FREQ2 cards will not be used unless selected in Case Control.
2. A frequency set selection is required for a Frequency Response problem.
3. A frequency set selection is required for Transient Response by Fourier methods.

4.6 BULK DATA DECK CARDS

(FROM REFS. 7 AND 4)

Input Data Card AERØ — Aerodynamic Physical Data

Description: Gives basic aerodynamic parameters.

Format and Example:

1	2	3	4	5	6	7	8	9	10
AERØ	ACSID	VELØCITY	REFC	RHØREF	SYMXZ	SYMXY			
AERØ	3	1.3+4	100.	1.-5		1			

Field	Contents
ACSID	Aerodynamic coordinate system identification (Integer ≥ 0). See Remark 2.
VELØCITY	Velocity (Real).
REFC	Reference length (for reduced frequency) (Real).
RHØREF	Reference density (Real).
SYMXZ	Symmetry key for aero coordinate x-z plane (Integer) (+1 for sym, =0 for no sym, -1 for anti-sym).
SYMXY	Symmetry key for aero coordinate x-y plane can be used to simulate ground effects (Integer), same code as SYMXZ.

Remarks:

1. This card is required for aerodynamic problems. Only one AERØ card is allowed.
2. The ACSID must be a rectangular coordinate system. Flow is in the positive x direction.
3. Reference length, b = REFC/2

$$\left(k = \frac{\omega b}{V} \right)$$

Input Data Card DAREA Dynamic Load Scale Factor

Description: This card is used in conjunction with the RLØAD1, RLØAD2, TLØAD1, and TLØAD2 data cards and defines the point where the dynamic load is to be applied with the scale (area) factor A.

Format and Example:

1	2	3	4	5	6	7	8	9	10
DAREA	SID	P	C	A	P	C	A		
DAREA	3	6	2	8.2	15	1	10.1		

Field	Contents
SID	Identification number of DAREA set (Integer > 0)
P	Grid or scalar point identification number (Integer > 0)
C	Component number (1-6 for grid point; blank or 0 for scalar point)
A	Scale (area) factor A for the designated coordinate (Real)

Remarks: One or two scale factors may be defined on a single card.

Input Data Card DPHASE Dynamic Load Phase Lead

Description: This card is used in conjunction with the RLØAD1 and RLØAD2 data cards to define the phase lead term θ in the equation of the loading function.

Format and Example:

1	2	3	4	5	6	7	8	9	10
DPHASE	SID	P	C	TH	P	C	TH		
DPHASE	4	21	6	2.1	8	6	7.2		

Field	Contents
SID	Identification number of DPHASE set (Integer > 0)
P	Grid or scalar point identification number (Integer > 0)
C	Component number (1-6 for grid point, 0 or blank for scalar point)
TH	Phase lead θ (in degrees) for designated coordinate (Real)

Remarks: One or two dynamic load phase lead terms may be defined on a single card.

Input Data Card FREQ Frequency List

Description: Defines a set of frequencies to be used in the solution of frequency response problems.

Format and Example:

1	2	3	4	5	6	7	8	9	10
FREQ	SID	F	F	F	F	F	F	F	abc
FREQ	3	2.98	3.05	17.9	21.3	25.6	28.8	31.2	ABC

+bc	F	F	F	F	F	F	F	F	
+BC	29.2	22.4	19.3						

-etc.-

Field	Contents
SID	Frequency set identification number (Integer > 0)
F	Frequency value (Real > 0.0)

Remarks:
1. The units for the frequencies are cycles per unit time.
2. Frequency sets must be selected in the Case Control Deck (FREQ=SID) to be used by NASTRAN.
3. All FREQ, FREQ1 and FREQ2 cards must have unique frequency set identification numbers.

Input Data Card MKAERØ2 Mach Number - Frequency Table

Description: Provides a list of Mach numbers or interblade phase angles (m) and reduced frequencies (k) for aerodynamic matrix calculation.

Format and Example:

1	2	3	4	5	6	7	8	9	10
MKAERØ2	m_1	k_1	m_2	k_2	m_3	k_3	m_4	k_4	
MKAERØ2	.10	.30	.10	.60	.70	.30	.70	1.0	

Field	Contents
m_i	List of Mach numbers (Real > 0.0).
k_i	List of reduced frequencies (Real > 0.0).

Remarks:
1. This card will cause the aerodynamic matrices to be computed for a set of parameter pairs.
2. Several MKAERØ2 cards may be in the deck.
3. Imbedded blank pairs are skipped.
4. Mach numbers are input for wing flutter and interblade phase angle for blade flutter and response.

Input Data Card RLØAD1 Frequency Response Dynamic Load

Description: Defines a frequency dependent dynamic load of the form

$$\{P(f)\} = \left\{A[C(f) + iD(f)]\, e^{i\{\theta - 2\pi f\tau\}}\right\}$$

for use in frequency response problems.

Format and Example:

1	2	3	4	5	6	7	8	9	10
RLØAD1	SID	L	M	N	TC	TD			
RLØAD1	5	3	6	9	1	2			

Field	Contents
SID	Set identification number (Integer > 0)
L	Identification number of DAREA or DAREAS and LØADC card set which defines A (Integer > 0)
M	Identification number of DELAY or DELAYS card set which defines τ (Integer $\geq$ 0)
N	Identification number of DPHASE or DPHASES card set which defines θ (Integer $\geq$ 0)
TC	Set identification number of TABLEDi card which gives C(f) (Integer $\geq$ 0; TC + TD > 0)
TD	Set identification number pf TABLEDi card which gives D(f) (Integer $\geq$ 0; TC + TD > 0)

Remarks:

1. If any of M, N, TC or TD are blank or zero, the corresponding τ, θ, C(f), or D(f) will be zero

2. Dynamic load sets must be selected in the Case Control Deck (DLØAD=SID) to be used by NASTRAN.

3. RLØAD1 loads may be combined with RLØAD2 loads only by specification on a DLØAD card. That is, the SID on a RLØAD1 card may not be the same as that on a RLØAD2 card.

4. SID must be unique for all RLØAD1, RLØAD2, TLØAD1 and TLØAD2 cards.

5. With automated multi-stage substructuring, DAREAS cards may only reference degrees of freedom in the boundary set of the solution structure.

6. When L references LØADC cards, DAREAS cards with the same set identification and non-zero loads must also exist.

Input Data Card STREAML1 Blade Streamline Data

Description: Defines grid points on the blade streamline from blade leading edge to blade trailing edge.

Format and Example:

1	2	3	4	5	6	7	8	9	10
STREAML1	SLN	G1	G2	G3	G4	G5	G6	G7	+ABC
STREAML1	3	2	4	6	8	10			

+ABC	G8	G9	-etc-						
+ABC									

Alternate Form:

STREAML1	SLN	GID1	"THRU"	GID2					
STREAML1	5	6	THRU	12					

Field	Contents
SLN	Streamline number (integer > 0).
Gi, GIDi	Grid point identification numbers (integer > 0).

Remarks:

1. This card is required for blade steady aeroelastic, blade flutter, and response problems.

2. There must be one STREAML1 card for each streamline on the blade. For blade dynamic problems, there must be an equal number of STREAML1 and STREAML2 cards.

3. The streamline numbers, SLN, must increase with increasing radial distance of the blade section from the axis of rotation. The lowest and the highest SLN, respectively, will be assumed to represent the blade sections closest to and farthest from the axis of rotation.

4. All grid points should be unique.

5. All grid points referenced by GID1 through GID2 must exist.

6. Each STREAML1 card must have the same number of grid points. The nodes must be input from the blade leading edge to the blade trailing edge in the correct positional order.

Input Data Card STREAML2 Blade Streamline Data

Description: Defines aerodynamic data for a blade streamline.

Format and Example:

STREAML2	SLN	NSTNS	STAGGER	CHORD	RADIUS/ DCBDZB	BSPACE	MACH	DEN	+abc
STREAML2	2	3	23.5	1.85	6.07	.886	.934	.066	

+abc	VEL	FLOWA/ SWEEP							
+ABC	1014.2	55.12							

Field	Contents
SLN	Streamline number (Integer >0)
NSTNS	Number of computing stations on the blade streamline. (3 $\leq$ NSTNS $\leq$ 10, Integer)
STAGGER	Blade stagger angle (-90.0 <stagger <90.0, degrees)
CHORD	Blade chord (real >0.0)
RADIUS/DCBDZB	Radius of streamline for dynamic analysis without sweep effects (real >0.0) or $\partial\bar{C}/\partial\bar{Z}$ for dynamic analysis with sweep effects. $\bar{C}$ is the swept chord and $\bar{Z}$ is the (local) spanwise reference direction (real)
BSPACE	Blade spacing (real >0.0)
MACH	Relative flow mach number at blade leading edge (real >0.0)
DEN	Gas density at blade leading edge (real >0.0)
VEL	Relative flow velocity at blade leading edge (real >0.0)
FLOWA/SWEEP	Relative flow angle at blade leading edge for dynamic analysis without sweep effects (-90.0 <FLOWA <90.0 degrees) or Blade sweep angle for dynamic analysis with sweep effects (-90.0 <SWEEP <90.0 degrees)

Remarks:

1. At least three (3) and no more than fifty (50) STREAML2 cards are required for a blade dynamic analysis.

2. The streamline number, SLN, must be the same as its corresponding SLN on a STREAML1 card. There must be a STREAML1 card for each STREAML2 card.

3. It is not required that all streamlines be used to define the aerodynamic matrices used in blade dynamic analysis.

4. For dynamic analysis with sweep effects, the use of the NASTRAN card is required as follows:

   NASTRAN SYSTEM (93) = 1

   Refer to Section 2.1 of the User's Manual and Section 6.3.1 of the Programmer's Manual for description and placement in the Executive Control Deck.

5. Dynamic analysis refers to both flutter and response analyses.

Input Data Card TABLED1 Dynamic Load Tabular Function

Description: Defines a tabular function for use in generating frequency-dependent and time-dependent dynamic loads.

Format and Example:

1	2	3	4	5	6	7	8	9	10
TABLED1	ID								+abc
TABLED1	32								ABC
+abc	X_1	Y_1	X_2	Y_2	X_3	Y_3	X_4	Y_4	
+BC	-3.0	6.9	2.0	5.6	3.0	5.6	ENDT		

Field	Contents
ID	Table identification number (Integer > 0)
X_i, Y_i	Tabular entries (Real)

Remarks:

1. The X_i must be in either ascending or decending order but not both.
2. Jumps between two points ($X_i = X_{i+1}$) are allowed, but not at the end points.
3. At least two entries must be present.
4. Any X-Y entry may be ignored by placing the BCD string "SKIP" in either of the two fields used for that entry.
5. The end of the table is indicated by the existence of the BCD string "ENDT" in either of the two fields following the last entry. An error is detected if any continuation cards follow the card containing the end-of-table flag "ENDT".
6. Each TABLEDi mnemonic infers the use of a specific algorithm. For TABLED1 type tables, this algorithm is

$$\boxed{Y = y_T(X)}$$

where X is input to the table and Y is returned. The table look-up $y_T(x)$, $x = X$, is performed using linear interpolation within the table and linear extrapolation outside the table using the last two end points at the appropriate table end. At jump points the average $y_T(x)$ is used. There are no error returns from this table look-up procedure.

7. Linear extrapolation is not used for Fourier Transform methods. The function is zero outside the range.

5. PROGRAM STRUCTURE

5.1 GENERAL

The AIRLOADS program is a stand-alone, transportable, all-FORTRAN program.

The program comprises a main program, 60 subroutine subprograms, and 4 function subprograms in about 6,600 lines of code.

The source of the AIRLOADS program on the CRAY 1-S computer system at NASA LeRC is called AIRSRCE. The executable version of the program on CRAY is called AIRLOAD.

All computations are carried out in three sequential Phases:

Phase 1 reads and processes input data,

Phase 2 performs all airloads computations, and

Phase 3 handles all output requests.

Each phase is entered by a call to its driver SUBROUTINE named PHASEi, i=1, 2, or 3 .

Subprograms for each phase are listed in Tables 5.1 through 5.3.

A cross reference list by program units is presented in Table 5.4. For every subprogram in the AIRLOADS program, this Table identifies the subprograms called by a given subprogram, and the

Table 5.1 Phase 1 Subprograms (Input Processing)

Subroutine		Function	
	PHASE1		INTEG1
	INTIAL		INTEG2
	CHECKI		REAL1
	CHECKR		REAL2
	INSORT	Total	4
	PAGE		
	REORDR		
	SUMMRY		
	HEADNG		
Total	9		

Table 5.2 Phase 2 Subprograms (Airloads Computations)

Subroutine	PHASE2	Subroutine	TRINT
	PYBAR		CRVFIT
	INTGRA		GAUSSR
	INICOM		OSCSUB
	BASIC		GAUSS
	CTRANS		OSCSUP
	T3BY3		SUBA
	SPCASE		SUBBB
	GNCASE		SUBC
	MULTPY		SUBD
	TBLSBR		ALAMDA
	SIKISI		AKP2
	STRML		AKAPPA
	XGCALC		DLKAPM
	PLTOG		ASYCON
	TSONIC		AKAPM
			DRKAPM
		Total	33

Table 5.3 Phase 3 Subprograms (Output Processing)

Subroutine	PHASE3
	TABLED
	DARDPH
	PUNCHB
	DLDRLD
	PUNCHC
	DENPUN
	PRINT6
	PRT1
	PRT2
	PRT3
	PRT4
	PRT5
	PRT6
	HB1FL0
	HB0FL0
	HB1FL1
	HB0FL1
Total	18

Table 5.4 Cross Reference List by Program Units

Program Unit	Calls	Called By
AIRLOD (Main)	PHASE1, PHASE2	-
PHASE1	HEADNG, INTIAL, PAGE, REORDR, CHECKI, CHECKR, INSORT, SUMMRY, INTEG1, INTEG2, REAL1, REAL2	AIRLOD (Main)
SUMMRY	PAGE	PHASE1
PHASE2	INICOM, CTRANS, BASIC, SPCASE, GNCASE, PLTOG, PHASE3	AIRLOD (Main)
PHASE3	PRINT6, PUNCHB, PUNCHC	PHASE2
PYBAR	INTGRA	SPCASE, GNCASE
BASIC	MULTPY	PHASE2
CTRANS	T3BY3	PHASE2
SPCASE	TBLSBR, STRML, XGCALC, OSCSUB, OSCSUP, PYBAR, TSONIC	PHASE2
GNCASE	TBLSBR, STRML, SIKISI, XGCALC, OSCSUB, OSCSUP, PYBAR, TSONIC	PHASE2
PUNCHB	DENPUN, SIKISI	PHASE3
HB1FL0	SIKISI, TABLED, DARDPH	PUNCHC
HB0FL0	TABLED, DARDPH	PUNCHC
HB1FL1	SIKISI, TABLED, DARDPH, DLDRLD	PUNCHC

(Continued)

Table 5.4 Continued

Program Unit	Calls	Called By
HB0FL1	DLDRLD, TABLED, DARDPH	PUNCHC
PUNCHC	SIKISI, HB0FL0, HB0FL1, HB1FL0, HB1FL1	PHASE3
PLTOG	TBLSBR, MULTPY	PHASE2
TSONIC	TRINT	SPCASE, GNCASE
TRINT	CRVFIT	TSONIC
CRVFIT	GAUSSR	TRINT
OSCSUB	GAUSS	SPCASE, GNCASE
OSCSUP	ASYCON, AKP2, SUBA	SPCASE, GNCASE
SUBA	AKAPM, DLKAPM, DRKAPM, ALAMDA, AKAPPA, SUBBB	OSCSUP
SUBBB	AKAPM, AKAPPA, SUBC	SUBA
SUBC	AKAPM, SUBD	SUBBB
SUBD	AKAPM	SUBC
PRINT6	PAGE, PRT1, TBLSBR, PRT2, PRT3, PRT4, PRT5, PRT6	PHASE3
PRT4	SIKISI	PRINT6
INTIAL	-	PHASE1
CHECKI	-	PHASE1
CHECKR	-	PHASE1

(Continued)

Table 5.4 Continued

Program Unit	Calls	Called By
INSORT	-	PHASE1
PAGE	-	PHASE1, SUMMRY, PRINT6
REORDR	-	PHASE1
HEADNG	-	PHASE1
INTEG1	-	PHASE1
INTEG2	-	PHASE1
REAL1	-	PHASE1
REAL2	-	PHASE1
INTGRA	-	PYBAR
INICOM	-	PHASE2
T3BY3	-	CTRANS
MULTPY	-	BASIC, PLTOG
TBLSBR	-	SPCASE, GNCASE, PLTOG, PRINT6
SIKISI	-	GNCASE, PUNCHB, HB1FL0, HB1FL1, PUNCHC, PRT4
STRML	-	SPCASE, GNCASE
XGCALC	-	SPCASE, GNCASE
GAUSSR	-	CRVFIT
GAUSS	-	OSCSUB
ALAMDA	-	SUBA
AKP2	-	OSCSUP
AKAPPA	-	SUBA, SUBBB

(Continued)

Table 5.4 Continued

Program Unit	Calls	Called By
DLKAPM	-	SUBA
ASYCON	-	OSCSUP
AKAPM	-	SUBA, SUBBB, SUBC, SUBD
DRKAPM	-	SUBA
TABLED	-	HB1FL0, HB0FL0, HB1FL1, HB0FL1
DARDPH	-	HB1FL0, HB0FL0, HB1FL1, HB0FL1
DLDRLD	-	HB1FL1, HB0FL1
DENPUN	-	PUNCHB
PRT1	-	PRINT6
PRT2	-	PRINT6
PRT3	-	PRINT6
PRT5	-	PRINT6
PRT6	-	PRINT6

(Concluded)

subprograms that call a given subprogram.

Extensive and frequent comments have been inserted in the AIRLOADS source code contained in AIRSRCE for easier understanding of the program logic.

Summary descriptions of AIRLOADS subprograms are presented, by phase, in the following subsections.

5.2 PHASE 1 SUBPROGRAMS

PHASE1. Reads and processes user input data. Checks the syntax of the data, and tests its validity, consistency, and completeness.

Due to its direct interface with the user input data, this routine embraces user-friendliness in its design. An echo of the entire input data is always printed. The data is then processed on a card-by-card basis. If errors are detected in the data, appropriate and descriptive error messages are printed out for user's information. If there are no errors in the data, the program prints a summary of the input data, and continues execution.

Detection of a data error does not necessarily terminate the execution immediately. Instead, the routine continues to process as much additional input data as is permitted by the error condition. Thus, in any given execution, the routine checks the validity of as much input data as possible.

CHECKI. Checks the validity of integer data values.

CHECKR. Checks the validity of real data values.

HEADNG. Prints the heading page of the output.

INSORT. Performs an in-core sorting of an array of entries based on a specified item in the entries.

INTEG1. Converts an array of 8 characters (single-field data) to an integer value.

INTEG2. Converts an array of 16 characters (double-field data) to an integer value.

INTIAL. Specifies the permissible input data card types and their allowability.

PAGE. Prints a new page of the output with the title, subtitle, date of run, and page number.

REAL1. Converts an array of 8 characters (single-field data) to a real value.

REAL2. Converts an array of 16 characters (double-field data) to a real value.

REORDR. Converts an array of 8 characters to a left-justified array with blank-fill to the right.

SUMMRY. Prints a summary of the input data.

5.3 PHASE 2 SUBPROGRAMS

PHASE2. This is the driver routine for all Phase 2 computations. Based on the flow type being uniform or non-uniform, this routine calls SPCASE or GNCASE. Airloads are transformed to the grid points displacement (global) coordinate systems by a call to PLTOG. Finally, PHASE3 is called to handle all output.

PYBAR. On a given subsonic or supersonic chord, this routine calculates the point loads in the positive $\overline{y}$ direction of the local (chord) coordinate system at all grid points on the chord.

INTGRA. Calculates pressure integrals between two grid points on given chord.

INICOM. Initializes arrays in some calculated common blocks.

BASIC. Calculates basic coordinates of all STREAML3 grid points for all chords.

CTRANS. Calls T3BY3 for transformation matrices for all coordinate systems used in the problem.

T3BY3. Calculates the 3 by 3 transformation matrices for rectangular, cylindrical, and spherical coordinate systems used in the problem.

SPCASE. Is the driver for uniform flow airloads calculations. Airloads are computed for all subsonic and supersonic chords. Transonic chords are identified, and TSONIC is called to interpolate loads. All airloads are computed in respective streamline coordinate systems.

GNCASE. This routine is the driver for non-uniform flow airloads calculations. Airloads are computed at all user-specified excitation frequencies. Computations are carried out similar to those in SPCASE.

MULTPY. Returns the product of two given matrices.

TBLSBR. Computes the coordinate transformation matrix from the basic to the local (chord) coordinate system on chord $\tilde{\bar{s}}$.

SIKISI. Computes the inter-blade phase angle, circumferential harmonic index, and sign of the factor relating the cosine and sine components of applied airloads.

STRML. Generates data for STREAML1 and STREAML2 bulk data cards.

XGCALC. On a given chord, calculates the x-coordinates of STREAML3 grid points in local (chord) coordinate systems.

PLTOG. For all grid points on all streamlines, transforms the grid point loads from the respective local (chord) coordinate systems to grid point global (displacement) coordinate systems.

TSONIC. Handles interpolation of transonic airloads based on Mach numbers. Calls TRINT.

TRINT. Performs interpolation for transonic airloads on a given chord. Calls CRVFIT.

CRVFIT. This routine is used by TRINT to obtain polynomial coefficients for known airloads distribution.

GAUSSR. Solves for X from A.X=B, real matrices.

OSCSUB. Calculates oscillatory pressure distribution on a given subsonic chord. Uses GAUSS.

OSCSUP. Calculates oscillatory pressure distribution on a given supersonic chord. Uses SUBA, SUBBB, SUBC, SUBD, ALAMDA, AKP2, AKAPPA, DLKAPM, ASYCON, AKAPM, and DRKAPM.

5.4 PHASE 3 SUBPROGRAMS

PHASE3. This is the driver routine for handling all output from AIRLOADS program. PRINT6 is called for printed output written to UNIT 6. If NASTRAN pre-processing is requested on NASOUT card, PUNCHB and PUNCHC are also called to write output to UNITS 7 and 8.

TABLED. Writes TABLED1 double-field cards to UNIT 8.

DARDPH. Writes DAREA and DPHASE cards to UNIT 8.

PUNCHB. Writes AERO, STREAML1, STREAML2, FREQ, MKAERO2, and all but KMAX and KMIN Parameter cards to UNIT 8.

DLDRLD. In non-uniform flow case, writes DLOAD and RLOAD1 bulk data cards to UNIT 8.

PUNCHC. Writes case control subcase definition cards to UNIT 7. Writes Parameters KMAX and KMIN to UNIT 8. Calls appropriate

C-2

routines (HB0FL0, HB0FL1, HB1FL0, or HB1FL1) based on hub and flow types to calculate RLOAD1 and related bulk data cards.

DENPUN. To breakdown and rearrange a given density value so that it may be written in an eight-column field with four digits following the decimal point.

PRINT6. Handles all output to UNIT 6.

PRT1. Writes streamline title on printed output.

PRT2. Writes streamline information, for a given streamline, on printed output.

PRT3. Prints the basic to local (chord) coordinate system transformation matrix.

PRT4. Prints oscillatory relative inflow information.

PRT5. Prints oscillatory airloads in streamline (chord) coordinate system.

PRT6. Prints oscillatory airloads in grid point global (displacement) coordinate systems.

HB1FL0. For flexible hub/disk and uniform inflow case, handles RLOAD1, DLOAD, TABLED1, DAREA, and DPHASE cards.

HB0FL0. For rigid hub/disk and uniform inflow case, handles RLOAD1, TABLED1, DAREA,and DPHASE cards.

HB1FL1. For flexible hub/disk and non-uniform inflow case, handles Parameters KMAX and KMIN, and TABLED1, DAREA, DPHASE, DLOAD, and RLOAD1 bulk data cards.

HBOFL1. For rigid hub/disk and non-uniform inflow, handles DLOAD, RLOAD1, TABLED1, DAREA, and DPHASE bulk data cards.

6. ILLUSTRATIVE EXAMPLES

6.1 GENERAL

Two examples are presented to illustrate the oscillatory airloads generation and NASTRAN pre-processing capabilities of the AIRLOADS program.

An eight-bladed single-rotation advanced turboprop with SR-3 (NASA designation) type swept blades is selected as an example of a turbosystem (Figure 6.1).

For both illustrative examples, the swept blades of the turboprop are set at angle of 60.8° with the plane of rotation, when measured at 3/4 tip radius. The prop rotates at a constant 8000 rpm. The freestream inflow density is 1.9034×10^{-3} lbf - sec^2/ft^4 . The hub is considered rigid as compared to blades.

6.2 EXAMPLE 1, UNIFORM INFLOW

For example 1, uniform inflow is considered at 0.798 Mach number and 873 fps inflow velocity. The prop axis is inclined at 2° with the absolute uniform inflow.

It is desired to use the AIRLOADS program to generate the oscillatory airloads distribution on the blades, and create the NASTRAN input files for case control and bulk data decks.

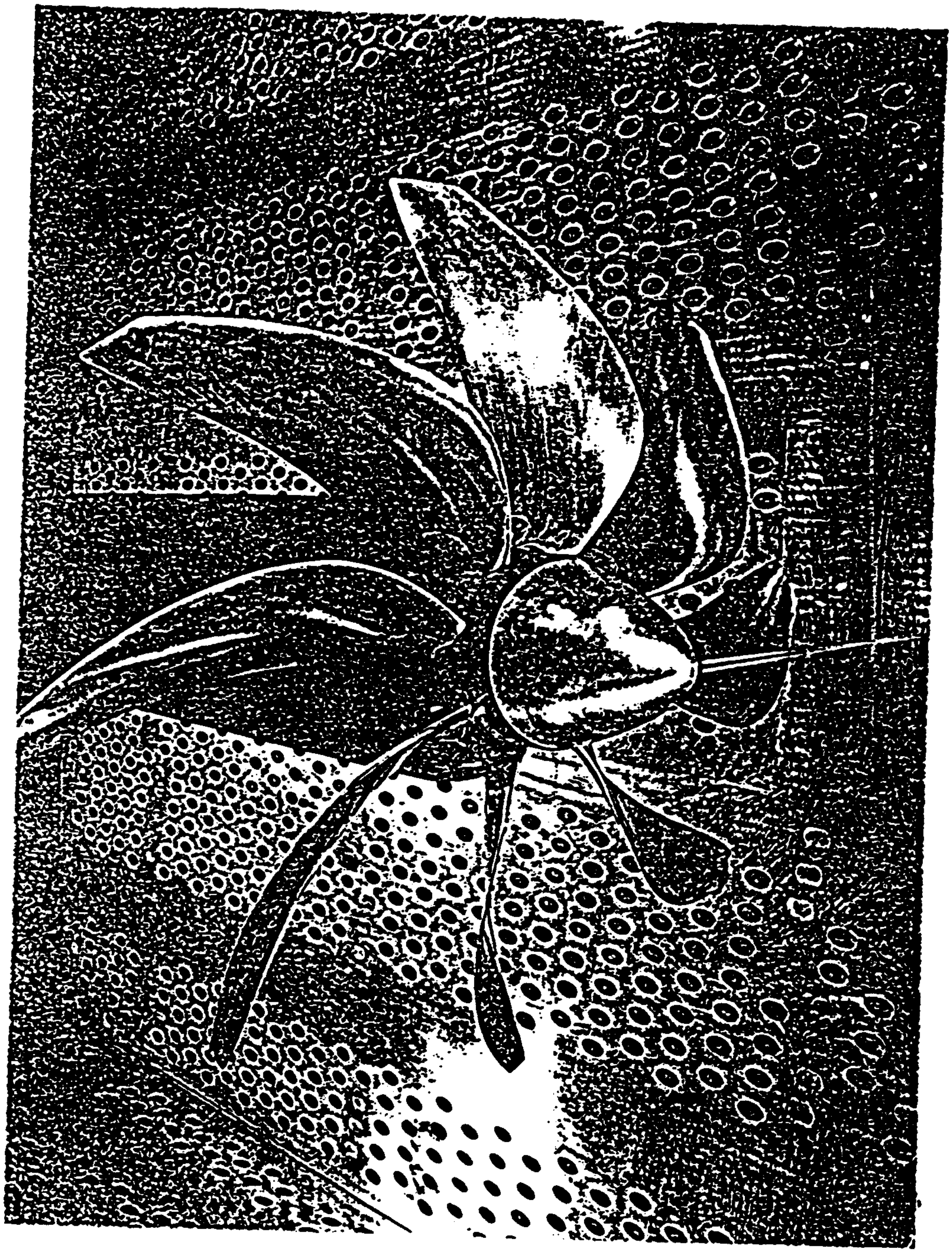


Figure 6.1 An Eight-Bladed Single-Rotation Advanced Turboprop

The aerodynamic model consisting of grid points selected on seven swept chords spanning the blade is shown in Figure 6.2. Oscillatory airloads are computed at these grid points. The only possible excitation frequency is given by the rotational speed of the turboprop, and equals 133.33 Hz.

The input and output for this example are presented in Sections 6.4 and 6.5, respectively.

6.3 EXAMPLE 2, NON-UNIFORM INFLOW

For example 2, a selective non-uniform inflow is prescribed as follows:

1. A rectangular tunnel coordinate system is specified, in terms of inertial coordinate system, as shown in Figure 6.3 . The inflow velocity is assumed along X_T axis. For all but the tip chord (Figure 6.2), this value is fixed at 873 fps, like in example 1 .

2. For the tip chord, the absolute inflow velocity is again restricted to X_T axis. The velocity is given by

$$V(\theta) = 873 + 87.3 \cos 2\theta \quad , \text{fps},$$

where $0 \leqslant \theta \leqslant 2\pi$ is measured in the direction of rotation. $\theta = 0$ is taken when the inertial and basic coordinate systems are parallel (see Appendix B).

3. An inflow Mach number of 0.798 based on the 873 fps velocity

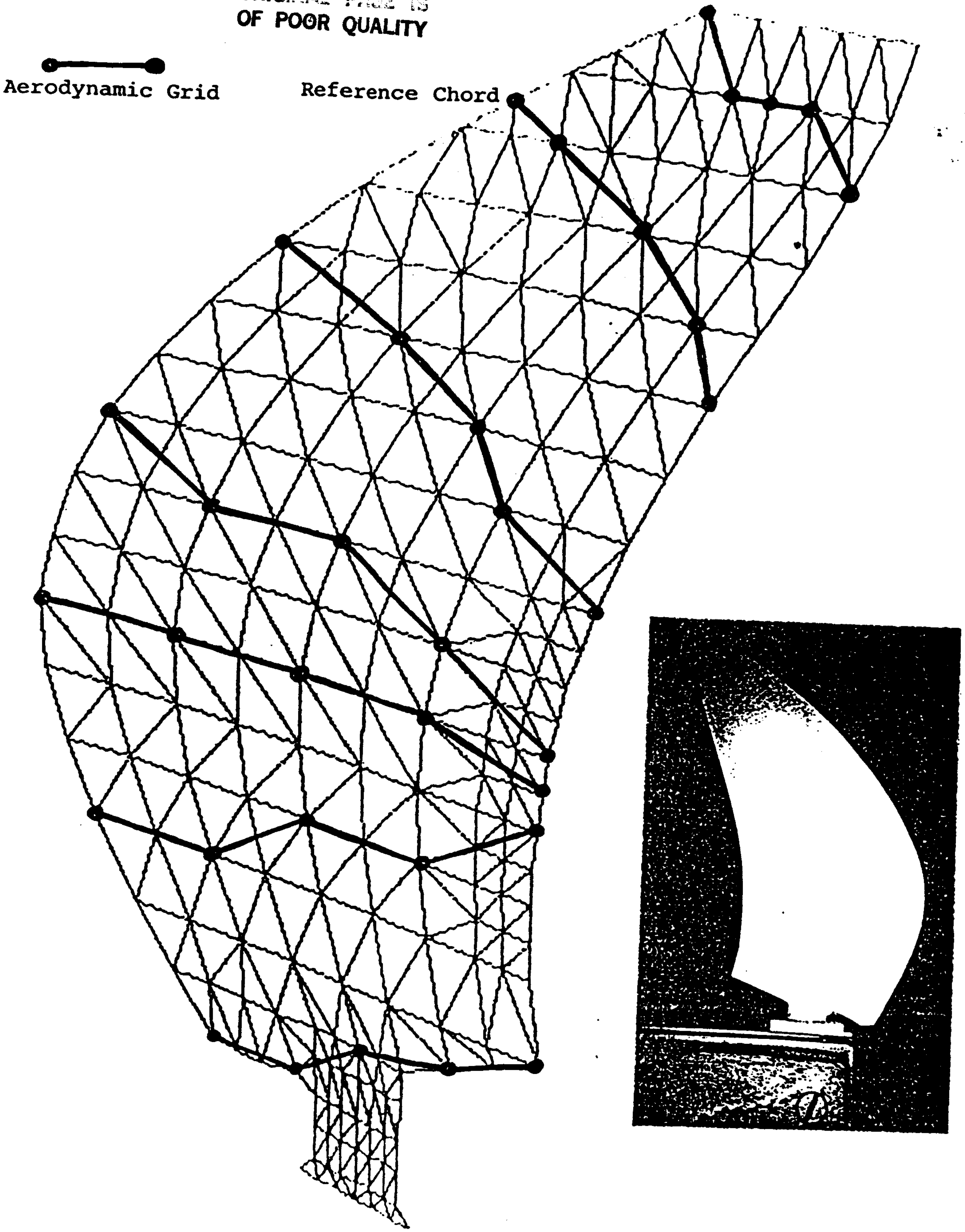


Figure 6.2 Aerodynamic Model of SR-3 Blade

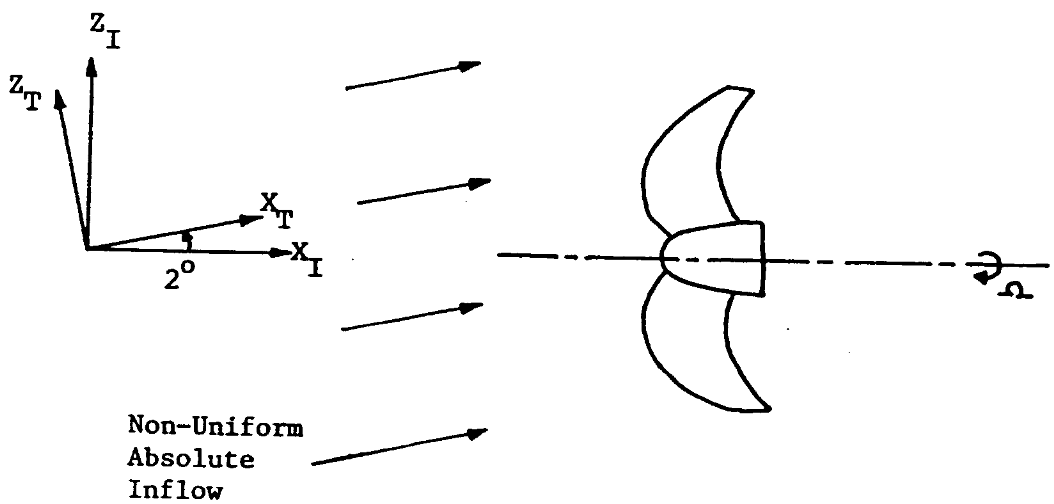


Figure 6.3 Freestream (Tunnel) Coordinate System for Example 2

uniquely establishes the speed of sound, like in example 1 .

AIRLOADS is used to calculate oscillatory airloads distribution on the blades at 1-, 2-, and 3- per-rev excitation frequencies.

Airloads at 1-per-rev frequency for all but the tip chord are directly comparable to those from example 1 .

The input and output, including pre-processed data files for NASTRAN, are presented in Sections 6.6 and 6.7 .

6.4 INPUT FOR UNIFORM INFLOW EXAMPLE

ORIGINAL PAGE IS
OF POOR QUALITY

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              OSCILLATORY AIRLOADS ON BLADES OF SR-3 ADVANCED TURBOPROP
                              EXAMPLE 1 , UNIFORM INFLOW
FLOTYP   UNIFORM 10476.
NLINES   7
NSEGS    8
RPS      133.33
INCANG   2.0
SSOUND   13128.
IREF     60
NASOUT   YES
MXMACH   .95
STREAML310        175        177        163        166        156
STREAML320        138        140        129        131        121
STREAML330        99         101        103        105        111
STREAML340        64         75         77         92         108
STREAML350        37         49         60         70         82
STREAML360        18         21         33         44         54
STREAML370        1          13         14         15         27
STREAML410        9.179E-8
STREAML420        9.179E-8
STREAML430        9.179E-8
STREAML440        9.179E-8
STREAML450        9.179E-8
STREAML460        9.179E-8
STREAML470        9.179E-8
CORD2R   77       0          .0         .0         .0         .0         .0         1.         +C2R
+C2R     10.      -0.618     .0
GRDSET            77
GRID             1          1.808      1.839      12.250
GRID             3          2.376      2.347      12.250
GRID             4          2.625      2.558      12.250
GRID             5          2.877      2.765      12.250
GRID             6          3.134      2.966      12.250
GRID             7          1.556      1.589      12.033
GRID             8          1.304      1.339      11.817
GRID             9          1.052      1.088      11.600
GRID             10         1.293      1.308      11.600
GRID             12         1.791      1.730      11.600
GRID             13         2.044      1.937      11.600
GRID             14         2.298      2.141      11.600
GRID             15         2.555      2.343      11.600
GRID             16         2.814      2.542      11.600
GRID             17         3.078      2.733      11.600
GRID             18         0.737      0.793      11.300
GRID             19         0.423      0.498      11.000
GRID             20         0.725      0.761      11.000
GRID             22         1.347      1.264      11.000
GRID             23         1.663      1.510      11.000
GRID             24         1.981      1.753      11.000
GRID             25         2.302      1.993      11.000
GRID             26         2.626      2.228      11.000
GRID             27         2.956      2.454      11.000
```

GRID	28	-0.160	-0.013	10.400
GRID	29	0.186	0.281	10.400
GRID	31	0.917	0.842	10.400
GRID	32	1.288	1.115	10.400
GRID	33	1.661	1.385	10.400
GRID	34	2.038	1.650	10.400
GRID	35	2.418	1.910	10.400
GRID	36	2.806	2.158	10.400
GRID	37	-0.702	-0.430	9.800
GRID	38	-0.306	-0.118	9.800
GRID	40	0.512	0.476	9.800
GRID	41	0.926	0.764	9.800
GRID	42	1.344	1.048	9.800
GRID	43	1.766	1.326	9.800
GRID	44	2.191	1.598	9.800
GRID	45	2.625	1.856	9.800
GRID	46	-1.193	-0.766	9.187
GRID	47	-0.760	-0.445	9.187
GRID	49	0.130	0.162	9.187
GRID	50	0.582	0.456	9.187
GRID	51	1.037	0.745	9.187
GRID	52	1.495	1.027	9.187
GRID	53	1.959	1.303	9.187
GRID	54	2.430	1.563	9.187
GRID	55	-1.612	-1.013	8.600
GRID	56	-1.149	-0.691	8.600
GRID	58	-0.199	-0.083	8.600
GRID	59	0.282	0.210	8.600
GRID	60	0.768	0.498	8.600
GRID	61	1.257	0.778	8.600
GRID	62	1.750	1.051	8.600
GRID	63	2.252	1.308	8.600
GRID	64	-1.985	-1.192	8.000
GRID	65	-1.496	-0.874	8.000
GRID	67	-0.494	-0.277	8.000
GRID	68	0.013	0.010	8.000
GRID	69	0.525	0.291	8.000
GRID	70	1.040	0.564	8.000
GRID	71	1.560	0.829	8.000
GRID	72	2.086	1.078	8.000
GRID	73	-2.301	-1.303	7.400
GRID	74	-1.790	-0.995	7.400
GRID	76	-0.747	-0.418	7.400
GRID	77	-0.218	-0.141	7.400
GRID	78	0.314	0.128	7.400
GRID	79	0.850	0.390	7.400
GRID	80	1.390	0.642	7.400
GRID	81	1.664	0.760	7.400
GRID	82	1.937	0.878	7.400
GRID	83	1.324	0.567	7.100
GRID	84	1.602	0.681	7.100
GRID	85	1.880	0.795	7.100
GRID	86	-2.556	-1.354	6.800
GRID	87	-2.028	-1.058	6.800
GRID	89	-0.948	-0.508	6.800
GRID	90	-0.402	-0.245	6.800
GRID	91	0.147	0.010	6.800
GRID	92	0.701	0.256	6.800
GRID	93	1.258	0.493	6.800
GRID	94	1.541	0.603	6.800
GRID	95	1.823	0.712	6.800
GRID	96	1.227	0.439	6.500
GRID	97	1.512	0.544	6.500
GRID	98	1.798	0.649	6.500
GRID	99	-2.716	-1.339	6.200
GRID	100	-2.173	-1.060	6.200

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GRID	102	-1.066	-0.542	6.200
GRID	103	-0.507	-0.296	6.200
GRID	104	0.057	-0.059	6.200
GRID	105	0.624	0.169	6.200
GRID	106	1.195	0.386	6.200
GRID	107	1.484	0.486	6.200
GRID	108	1.772	0.586	6.200
GRID	109	1.195	0.352	5.900
GRID	110	1.484	0.447	5.900
GRID	111	1.773	0.542	5.900
GRID	112	-2.748	-1.254	5.600
GRID	113	-2.198	-0.996	5.600
GRID	115	-1.083	-0.519	5.600
GRID	116	-0.519	-0.294	5.600
GRID	117	0.049	-0.079	5.600
GRID	118	0.620	0.125	5.600
GRID	119	1.195	0.318	5.600
GRID	120	1.485	0.408	5.600
GRID	121	1.775	0.498	5.600
GRID	122	1.216	0.301	5.300
GRID	123	1.504	0.386	5.300
GRID	124	1.792	0.471	5.300
GRID	125	-2.670	-1.111	5.000
GRID	126	-2.124	-0.880	5.000
GRID	128	-1.017	-0.453	5.000
GRID	129	-0.459	-0.254	5.000
GRID	130	0.104	-0.065	5.000
GRID	131	0.669	0.114	5.000
GRID	132	1.238	0.283	5.000
GRID	133	1.523	0.363	5.000
GRID	134	1.809	0.444	5.000
GRID	135	1.274	0.278	4.700
GRID	136	1.556	0.355	4.700
GRID	137	1.837	0.432	4.700
GRID	138	-2.513	-0.927	4.400
GRID	139	-1.976	-0.727	4.400
GRID	141	-0.891	-0.359	4.400
GRID	142	-0.344	-0.189	4.400
GRID	143	0.206	-0.028	4.400
GRID	144	0.758	0.125	4.400
GRID	145	1.311	0.274	4.400
GRID	146	1.588	0.347	4.400
GRID	147	1.865	0.420	4.400
GRID	148	-2.273	-0.686	3.715
GRID	149	-1.742	-0.524	3.715
GRID	151	-0.672	-0.233	3.715
GRID	152	-0.133	-0.099	3.715
GRID	153	0.406	0.031	3.715
GRID	154	0.946	0.159	3.715
GRID	155	1.485	0.291	3.715
GRID	156	2.021	0.433	3.715
GRID	157	-2.051	-0.483	3.180
GRID	158	-1.675	-0.394	3.180
GRID	159	-1.296	-0.309	3.180
GRID	161	-0.548	-0.089	3.180
GRID	162	-0.274	-0.044	3.180
GRID	163	0.000	0.000	3.180
GRID	164	0.274	0.044	3.180
GRID	165	0.548	0.089	3.180
GRID	166	1.037	0.214	3.358
GRID	167	1.527	0.328	3.537
GRID	168	-0.548	-0.089	2.930
GRID	169	-0.365	-0.059	2.930
GRID	170	-0.183	-0.030	2.930
GRID	171	0.000	0.000	2.930
GRID	172	0.183	0.030	2.930

GRID	173	0.365	0.059	2.930
GRID	174	0.548	0.089	2:930
GRID	175	-1.804	-0.270	2.650
GRID	176	-1.188	-0.182	2.650
GRID	177	-0.750	-0.123	2.740
GRID	178	-0.550	-0.072	2.600
GRID	179	-0.367	-0.048	2.600
GRID	180	-0.184	-0.024	2.600
GRID	181	0.000	0.000	2.600
GRID	182	0.184	0.024	2.600
GRID	183	0.367	0.048	2.600
GRID	184	0.550	0.072	2.600
GRID	185	-0.550	-0.072	2.350
GRID	186	-0.367	-0.048	2.350
GRID	187	-0.184	-0.024	2.350
GRID	188	0.000	0.000	2.350
GRID	189	0.184	0.024	2.350
GRID	190	0.367	0.048	2.350
GRID	191	0.550	0.072	2.350
GRID	192	-0.550	-0.072	2.070
GRID	193	-0.367	-0.048	2.070
GRID	194	-0.184	-0.024	2.070
GRID	195	0.000	0.000	2.070
GRID	196	0.184	0.024	2.070
GRID	197	0.367	0.048	2.070
GRID	198	0.550	0.072	2.070
GRID	199	-0.699	-0.091	1.920
GRID	200	-0.466	-0.061	1.920
GRID	201	-0.233	-0.030	1.920
GRID	202	0.000	0.000	1.920
GRID	203	0.233	0.030	1.920
GRID	204	0.466	0.061	1.920
GRID	205	0.699	0.091	1.920
GRID	206	-1.496	-0.226	2.650
GRID	2	2.129	2.133	12.250
GRID	11	1.541	1.520	11.600
GRID	21	1.034	1.014	11.000
GRID	30	0.550	0.564	10.400
GRID	39	0.101	0.182	9.800
GRID	48	-0.317	-0.138	9.187
GRID	57	-0.677	-0.383	8.600
GRID	66	-0.998	-0.572	8.000
GRID	75	-1.271	-0.702	7.400
GRID	88	-1.490	-0.779	6.800
GRID	101	-1.621	-0.796	6.200
GRID	114	-1.642	-0.753	5.600
GRID	127	-1.572	-0.662	5.000
GRID	140	-1.435	-0.538	4.400
GRID	150	-1.208	-0.374	3.715
GRID	160	-0.917	-0.229	3.180

6.5 OUTPUT FROM UNIFORM INFLOW EXAMPLE

AIRLOADS

A PROGRAM TO COMPUTE OSCILLATORY AIRLOADS IMPOSED ON BLADES OF TURBOSYSTEMS IN SPATIALLY NON-UNIFORM INFLOW FIELDS

OSCILLATORY AIRLOADS ON BLADES OF SR-3 ADVANCED TURBOPROP

EXAMPLE 1 , UNIFORM INFLOW

INPUT DATA ECHO

```
            FIELDS  ****1***----2---****3***----4---****5***----6---****7***----8---****9***---1Ø---

CARD        COLUMN  ØØØØØØØØØ1111111111222222222233333333334444444444555555555566666666667777777778
COUNT        NOS.   12345678901234567890123456789012345678901234567890123456789012345678901234567890

  1                          OSCILLATORY AIRLOADS ON BLADES OF SR-3 ADVANCED TURBOPROP
  2                                         EXAMPLE 1 , UNIFORM INFLOW
  3                 FLOTYP   UNIFORM 1Ø476.
  4                 NLINES   7
  5                 NSEGS    8
  6                 RPS      133.33
  7                 INCANG   2.Ø
  8                 SSOUND   13128.
  9                 IREF     6Ø
 1Ø                 NASOUT   YES
 11                 MXMACH   .95
 12                 STREAML31Ø      175       177       163       166       156
 13                 STREAML32Ø      138       14Ø       129       131       121
 14                 STREAML33Ø      99        1Ø1       1Ø3       1Ø5       111
 15                 STREAML34Ø      64        75        77        92        1Ø8
 16                 STREAML35Ø      37        49        6Ø        7Ø        82
 17                 STREAML36Ø      18        21        33        44        54
 18                 STREAML37Ø      1         13        14        15        27
 19                 STREAML41Ø      9.179E-8
 2Ø                 STREAML42Ø      9.179E-8
 21                 STREAML43Ø      9.179E-8
 22                 STREAML44Ø      9.179E-8
 23                 STREAML45Ø      9.179E-8
 24                 STREAML46Ø      9.179E-8
 25                 STREAML47Ø      9.179E-8
 26                 CORD2R   77     Ø         .Ø        .Ø        .Ø        .Ø        .Ø        1.        +C2R
 27                 +C2R     1Ø.    -Ø.618    .Ø
 28                 GRDSET          77
 29                 GRID            1                   1.8Ø8     1.839     12.25Ø
 3Ø                 GRID            3                   2.376     2.347     12.25Ø
 31                 GRID            4                   2.625     2.558     12.25Ø
 32                 GRID            5                   2.877     2.765     12.25Ø
 33                 GRID            6                   3.134     2.966     12.25Ø
 34                 GRID            7                   1.556     1.589     12.Ø33
 35                 GRID            8                   1.3Ø4     1.339     11.817
 36                 GRID            9                   1.Ø52     1.Ø88     11.6ØØ
 37                 GRID           1Ø                   1.293     1.3Ø8     11.6ØØ
 38                 GRID           12                   1.791     1.73Ø     11.6ØØ
 39                 GRID           13                   2.Ø44     1.937     11.6ØØ
```

INPUT DATA ECHO

```
                FIELDS  ****1***----2---****3***----4---****5***----6---****7***----8---****9***---10---

CARD            COLUMN  00000000011111111112222222222333333333344444444445555555555666666666677777777778
COUNT            NOS.   12345678901234567890123456789012345678901234567890123456789012345678901234567890

  40                    GRID            14              2.298   2.141  11.600
  41                    GRID            15              2.555   2.343  11.600
  42                    GRID            16              2.814   2.542  11.600
  43                    GRID            17              3.078   2.733  11.600
  44                    GRID            18              0.737   0.793  11.300
  45                    GRID            19              0.423   0.498  11.000
  46                    GRID            20              0.725   0.761  11.000
  47                    GRID            22              1.347   1.264  11.000
  48                    GRID            23              1.663   1.510  11.000
  49                    GRID            24              1.981   1.753  11.000
  50                    GRID            25              2.302   1.993  11.000
  51                    GRID            26              2.626   2.228  11.000
  52                    GRID            27              2.956   2.454  11.000
  53                    GRID            28             -0.168  -0.013  10.400
  54                    GRID            29              0.186   0.281  10.400
  55                    GRID            31              0.917   0.842  10.400
  56                    GRID            32              1.288   1.115  10.400
  57                    GRID            33              1.661   1.385  10.400
  58                    GRID            34              2.038   1.650  10.400
  59                    GRID            35              2.418   1.910  10.400
  60                    GRID            36              2.806   2.158  10.400
  61                    GRID            37             -0.702  -0.430   9.800
  62                    GRID            38             -0.306  -0.118   9.800
  63                    GRID            40              0.512   0.476   9.800
  64                    GRID            41              0.926   0.764   9.800
  65                    GRID            42              1.344   1.048   9.800
  66                    GRID            43              1.766   1.326   9.800
  67                    GRID            44              2.191   1.598   9.800
  68                    GRID            45              2.625   1.856   9.800
  69                    GRID            46             -1.193  -0.766   9.187
  70                    GRID            47             -0.760  -0.445   9.187
  71                    GRID            49              0.130   0.162   9.187
  72                    GRID            50              0.582   0.456   9.187
  73                    GRID            51              1.037   0.745   9.187
  74                    GRID            52              1.495   1.027   9.187
  75                    GRID            53              1.959   1.303   9.187
  76                    GRID            54              2.430   1.563   9.187
  77                    GRID            55             -1.612  -1.013   8.600
  78                    GRID            56             -1.149  -0.691   8.600
```

INPUT DATA ECHO

```
              FIELDS   ****1***----2---****3***----4---****5***----6---****7***----8---****9***---10---
 CARD         COLUMN   00000000011111111112222222222333333333344444444445555555555666666666677777777778
 COUNT         NOS.    12345678901234567890123456789012345678901234567890123456789012345678901234567890
   79                  GRID      58            -0.199  -0.083   8.600
   80                  GRID      59             0.282   0.210   8.600
   81                  GRID      60             0.768   0.498   8.600
   82                  GRID      61             1.257   0.778   8.600
   83                  GRID      62             1.750   1.051   8.600
   84                  GRID      63             2.252   1.308   8.600
   85                  GRID      64            -1.985  -1.192   8.000
   86                  GRID      65            -1.496  -0.874   8.000
   87                  GRID      67            -0.494  -0.277   8.000
   88                  GRID      68             0.013   0.010   8.000
   89                  GRID      69             0.525   0.291   8.000
   90                  GRID      70             1.040   0.564   8.000
   91                  GRID      71             1.560   0.829   8.000
   92                  GRID      72             2.086   1.078   8.000
   93                  GRID      73            -2.301  -1.303   7.400
   94                  GRID      74            -1.790  -0.995   7.400
   95                  GRID      76            -0.747  -0.418   7.400
   96                  GRID      77            -0.218  -0.141   7.400
   97                  GRID      78             0.314   0.128   7.400
   98                  GRID      79             0.850   0.390   7.400
   99                  GRID      80             1.390   0.642   7.400
  100                  GRID      81             1.664   0.760   7.400
  101                  GRID      82             1.937   0.878   7.400
  102                  GRID      83             1.324   0.567   7.100
  103                  GRID      84             1.602   0.681   7.100
  104                  GRID      85             1.880   0.795   7.100
  105                  GRID      86            -2.556  -1.354   6.800
  106                  GRID      87            -2.028  -1.058   6.800
  107                  GRID      89            -0.948  -0.508   6.800
  108                  GRID      90            -0.402  -0.245   6.800
  109                  GRID      91             0.147   0.010   6.800
  110                  GRID      92             0.701   0.256   6.800
  111                  GRID      93             1.258   0.493   6.800
  112                  GRID      94             1.541   0.603   6.800
  113                  GRID      95             1.823   0.712   6.800
  114                  GRID      96             1.227   0.439   6.500
  115                  GRID      97             1.512   0.544   6.500
  116                  GRID      98             1.798   0.649   6.500
  117                  GRID      99            -2.716  -1.339   6.200
```

OSCILLATORY AIRLOADS ON BLADES OF SR-3 ADVANCED TURBOPROP DATE OF RUN -- 07/29/85 PAGE 4
EXAMPLE 1 , UNIFORM INFLOW

INPUT DATA ECHO

```
                FIELDS ****1***----2---****3***----4---****5***----6---****7***----8---****9***----10---
CARD    COLUMN  00000000011111111112222222222333333333344444444445555555555666666666677777777778
COUNT    NOS.   12345678901234567890123456789012345678901234567890123456789012345678901234567890
 118            GRID    100          -2.173  -1.060   6.200
 119            GRID    102          -1.066  -0.542   6.200
 120            GRID    103          -0.507  -0.296   6.200
 121            GRID    104           0.057  -0.059   6.200
 122            GRID    105           0.624   0.169   6.200
 123            GRID    106           1.195   0.386   6.200
 124            GRID    107           1.484   0.486   6.200
 125            GRID    108           1.772   0.586   6.200
 126            GRID    109           1.195   0.352   5.900
 127            GRID    110           1.484   0.447   5.900
 128            GRID    111           1.773   0.542   5.900
 129            GRID    112          -2.748  -1.254   5.600
 130            GRID    113          -2.198  -0.996   5.600
 131            GRID    115          -1.083  -0.519   5.600
 132            GRID    116          -0.519  -0.294   5.600
 133            GRID    117           0.049  -0.079   5.600
 134            GRID    118           0.620   0.125   5.600
 135            GRID    119           1.195   0.318   5.600
 136            GRID    120           1.485   0.408   5.600
 137            GRID    121           1.775   0.498   5.600
 138            GRID    122           1.216   0.301   5.300
 139            GRID    123           1.504   0.386   5.300
 140            GRID    124           1.792   0.471   5.300
 141            GRID    125          -2.670  -1.111   5.000
 142            GRID    126          -2.124  -0.880   5.000
 143            GRID    128          -1.017  -0.453   5.000
 144            GRID    129          -0.459  -0.254   5.000
 145            GRID    130           0.104  -0.065   5.000
 146            GRID    131           0.669   0.114   5.000
 147            GRID    132           1.238   0.283   5.000
 148            GRID    133           1.523   0.363   5.000
 149            GRID    134           1.809   0.444   5.000
 150            GRID    135           1.274   0.278   4.700
 151            GRID    136           1.556   0.355   4.700
 152            GRID    137           1.837   0.432   4.700
 153            GRID    138          -2.513  -0.927   4.400
 154            GRID    139          -1.976  -0.727   4.400
 155            GRID    141          -0.891  -0.359   4.400
 156            GRID    142          -0.344  -0.189   4.400
```

INPUT DATA ECHO

```
         FIELDS  ****1***----2---****3***----4---****5***----6---****7***----8---****9***---1Ø---
CARD     COLUMN  ØØØØØØØØØ1111111111222222222233333333334444444444555555555566666666667777777778
COUNT     NOS.   12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

CARD COUNT					
157	GRID	143	Ø.2Ø6	-Ø.Ø28	4.4ØØ
158	GRID	144	Ø.758	Ø.125	4.4ØØ
159	GRID	145	1.311	Ø.274	4.4ØØ
16Ø	GRID	146	1.588	Ø.347	4.4ØØ
161	GRID	147	1.865	Ø.42Ø	4.4ØØ
162	GRID	148	-2.273	-Ø.686	3.715
163	GRID	149	-1.742	-Ø.524	3.715
164	GRID	151	-Ø.672	-Ø.233	3.715
165	GRID	152	-Ø.133	-Ø.Ø99	3.715
166	GRID	153	Ø.4Ø6	Ø.Ø31	3.715
167	GRID	154	Ø.946	Ø.159	3.715
168	GRID	155	1.485	Ø.291	3.715
169	GRID	156	2.Ø21	Ø.433	3.715
17Ø	GRID	157	-2.Ø51	-Ø.483	3.18Ø
171	GRID	158	-1.675	-Ø.394	3.18Ø
172	GRID	159	-1.296	-Ø.3Ø9	3.18Ø
173	GRID	161	-Ø.548	-Ø.Ø89	3.18Ø
174	GRID	162	-Ø.274	-Ø.Ø44	3.18Ø
175	GRID	163	Ø.ØØØ	Ø.ØØØ	3.18Ø
176	GRID	164	Ø.274	Ø.Ø44	3.18Ø
177	GRID	165	Ø.548	Ø.Ø89	3.18Ø
178	GRID	166	1.Ø37	Ø.214	3.358
179	GRID	167	1.527	Ø.328	3.537
18Ø	GRID	168	-Ø.548	-Ø.Ø89	2.93Ø
181	GRID	169	-Ø.365	-Ø.Ø59	2.93Ø
182	GRID	17Ø	-Ø.183	-Ø.Ø3Ø	2.93Ø
183	GRID	171	Ø.ØØØ	Ø.ØØØ	2.93Ø
184	GRID	172	Ø.183	Ø.Ø3Ø	2.93Ø
185	GRID	173	Ø.365	Ø.Ø59	2.93Ø
186	GRID	174	Ø.548	Ø.Ø89	2.93Ø
187	GRID	175	-1.8Ø4	-Ø.27Ø	2.65Ø
188	GRID	176	-1.188	-Ø.182	2.65Ø
189	GRID	177	-Ø.75Ø	-Ø.123	2.74Ø
19Ø	GRID	178	-Ø.55Ø	-Ø.Ø72	2.6ØØ
191	GRID	179	-Ø.367	-Ø.Ø48	2.6ØØ
192	GRID	18Ø	-Ø.184	-Ø.Ø24	2.6ØØ
193	GRID	181	Ø.ØØØ	Ø.ØØØ	2.6ØØ
194	GRID	182	Ø.184	Ø.Ø24	2.6ØØ
195	GRID	183	Ø.367	Ø.Ø48	2.6ØØ

INPUT DATA ECHO

```
          FIELDS  ****1***----2---****3***----4---****5***----6---****7***----8---****9***---10---

CARD      COLUMN  00000000011111111112222222222333333333344444444445555555555666666666677777777778
COUNT      NOS.   12345678901234567890123456789012345678901234567890123456789012345678901234567890
```

CARD COUNT					
196	GRID	184	0.550	0.072	2.600
197	GRID	185	-0.550	-0.072	2.350
198	GRID	186	-0.367	-0.048	2.350
199	GRID	187	-0.184	-0.024	2.350
200	GRID	188	0.000	0.000	2.350
201	GRID	189	0.184	0.024	2.350
202	GRID	190	0.367	0.048	2.350
203	GRID	191	0.550	0.072	2.350
204	GRID	192	-0.550	-0.072	2.070
205	GRID	193	-0.367	-0.048	2.070
206	GRID	194	-0.184	-0.024	2.070
207	GRID	195	0.000	0.000	2.070
208	GRID	196	0.184	0.024	2.070
209	GRID	197	0.367	0.048	2.070
210	GRID	198	0.550	0.072	2.070
211	GRID	199	-0.699	-0.091	1.920
212	GRID	200	-0.466	-0.061	1.920
213	GRID	201	-0.233	-0.030	1.920
214	GRID	202	0.000	0.000	1.920
215	GRID	203	0.233	0.030	1.920
216	GRID	204	0.466	0.061	1.920
217	GRID	205	0.699	0.091	1.920
218	GRID	206	-1.496	-0.226	2.650
219	GRID	2	2.129	2.133	12.250
220	GRID	11	1.541	1.520	11.600
221	GRID	21	1.034	1.014	11.000
222	GRID	30	0.550	0.564	10.400
223	GRID	39	0.101	0.182	9.800
224	GRID	48	-0.317	-0.138	9.187
225	GRID	57	-0.677	-0.383	8.600
226	GRID	66	-0.998	-0.572	8.000
227	GRID	75	-1.271	-0.702	7.400
228	GRID	88	-1.490	-0.779	6.800
229	GRID	101	-1.621	-0.796	6.200
230	GRID	114	-1.642	-0.753	5.600
231	GRID	127	-1.572	-0.662	5.000
232	GRID	140	-1.435	-0.538	4.400
233	GRID	150	-1.208	-0.374	3.715
234	GRID	160	-0.917	-0.229	3.180

*** NO ERRORS FOUND -- EXECUTION CONTINUING ***

S U M M A R Y   O F   I N P U T   D A T A

```
NUMBER OF STREAMLINES ........................... (NLINES ) ......       7
TYPE OF FLOW .................................... (FLOTYP ) ......  UNIFORM
NUMBER OF BLADE SEGMENTS ........................ (NSEGS  ) ......       8
ROTATIONAL SPEED ................................ (RPS    ) ......   133.33ØØ
ROTATIONAL AXIS INCLINATION ANGLE ............... (INCANG ) ......     2.ØØØØ DEG.
SPEED OF SOUND .................................. (SSOUND ) ......  13128.ØØØØ
UPPER MACH NUMBER LIMIT FOR SUBSONIC FLOW ....... (MXMACH ) ......     Ø.95ØØ
LOWER MACH NUMBER LIMIT FOR SUPERSONIC FLOW ..... (DEFAULT) ......     1.Ø1ØØ
REFERENCE STREAMLINE ID ......................... (IREF   ) ......      6Ø
TYPE OF HUB ..................................... (DEFAULT) ......  RIGID
NASTRAN-TYPE OUTPUT DESIRED ..................... (NASOUT ) ......  YES

UNIFORM INFLOW VELOCITY .................................... 1Ø476.ØØØØ
NUMBER OF GRID POINTS ......................................      35
NO. OF RECT. COORDINATE SYSTEMS DEFINED ....................       1
```

OSCILLATORY AIRLOADS ON BLADES OF SR-3 ADVANCED TURBOPROP
EXAMPLE 1 , UNIFORM INFLOW

DATE OF RUN -- Ø7/29/85 PAGE 8

STREAMLINE ID = 1Ø

STREAMLINE COUNT FROM BLADE ROOT	1				
OSCILLATORY AIRLOADS COMPUTED AT GRID POINTS WITH ID'S	175	177	163	166	156
STAGGER ANGLE (DEG.)	7.792				
CHORD	4.Ø32				
RATE OF CHANGE OF CHORD ALONG SPANWISE REFERENCE LINE	Ø.322				
BLADE SPACING	2.Ø85				
MACH NO. BASED ON UNIFORM PART OF RELATIVE INFLOW VELOCITY	Ø.786				
INFLOW DENSITY	Ø.9179ØØØE-Ø7				
UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY	Ø.1Ø31659E+Ø5				
SWEEP ANGLE (DEG.)	-14.878				
STRIP WIDTH AT LEADING EDGE	Ø.961				
STRIP WIDTH AT TRAILING EDGE	Ø.917				

STREAMLINE ID = 1Ø

BASIC TO STREAMLINE COORDINATE SYSTEM TRANSFORMATION

Ø.958	Ø.116	Ø.264
-Ø.144	Ø.971	Ø.Ø99
-Ø.245	-Ø.133	Ø.947

OSCILLATORY RELATIVE INFLOW INFORMATION

(SEMI-CHORD, AND UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY FOR THIS STREAMLINE HAVE BEEN USED TO NON-DIMENSIONALIZE INDICATED VARIABLES IN THE FOLLOWING TABLE)

EXCITATION FREQUENCY		OSCILLATORY VELOCITY (NON-DIM.)		REDUCED FREQUENCY	INTER-BLADE PHASE ANGLE
(PER REV)	(CYCLES/TIME)	(REAL)	(IMAG.)	(NON-DIM.)	(DEG.)
1	133.33Ø	Ø.35Ø36E-Ø2	-Ø.34422E-Ø1	Ø.164	-45.ØØØ

STREAMLINE ID = 1Ø

1 PER REV OSCILLATORY AIRLOADS

(** IN STREAMLINE COORDINATE SYSTEM **)

GRID POINT ID	DISTANCE FROM L.E. ALONG CHORD, NON-DIM. BY SEMI-CHORD	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)
175	Ø.ØØØ	-Ø.9Ø728E+ØØ	-Ø.71656E+ØØ
177	Ø.52Ø	-Ø.72335E+ØØ	-Ø.78862E+ØØ
163	Ø.942	-Ø.29155E+ØØ	-Ø.56334E+ØØ
166	1.471	-Ø.13386E+ØØ	-Ø.45668E+ØØ
156	2.ØØØ	-Ø.14169E-Ø1	-Ø.15137E+ØØ

(** IN GRID POINT DISPLACEMENT COORDINATE SYSTEMS **)

GRID POINT ID	DISP. C.S. ID	LOAD IN T1-DIR. (REAL)	LOAD IN T1-DIR. (IMAG.)	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)	LOAD IN T3-DIR. (REAL)	LOAD IN T3-DIR. (IMAG.)
175	Ø	Ø.131Ø4E+ØØ	Ø.1Ø349E+ØØ	-Ø.88125E+ØØ	-Ø.696Ø1E+ØØ	-Ø.89696E-Ø1	-Ø.7Ø841E-Ø1
177	Ø	Ø.1Ø447E+ØØ	Ø.1139ØE+ØØ	-Ø.7Ø261E+ØØ	-Ø.766ØØE+ØØ	-Ø.71513E-Ø1	-Ø.77965E-Ø1
163	Ø	Ø.421Ø8E-Ø1	Ø.81363E-Ø1	-Ø.28318E+ØØ	-Ø.5471ØE+ØØ	-Ø.28823E-Ø1	-Ø.55693E-Ø1
166	Ø	Ø.19333E-Ø1	Ø.65959E-Ø1	-Ø.13ØØ2E+ØØ	-Ø.44358E+ØØ	-Ø.13233E-Ø1	-Ø.45149E-Ø1
156	Ø	Ø.2Ø465E-Ø2	Ø.21863E-Ø1	-Ø.13763E-Ø1	-Ø.147Ø3E+ØØ	-Ø.14ØØ8E-Ø2	-Ø.14965E-Ø1

(Similar output for Streamline ID's 20 through 50 appears on pages 11-22)

STREAMLINE ID = 6Ø

STREAMLINE COUNT FROM BLADE ROOT	6				
OSCILLATORY AIRLOADS COMPUTED AT GRID POINTS WITH ID'S	18	21	33	44	54
STAGGER ANGLE (DEG.)	24.776				
CHORD	2.815				
RATE OF CHANGE OF CHORD ALONG SPANWISE REFERENCE LINE	-Ø.57Ø				
BLADE SPACING	8.894				
MACH NO. BASED ON UNIFORM PART OF RELATIVE INFLOW VELOCITY	Ø.698				
INFLOW DENSITY	Ø.9179ØØØE-Ø7				
UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY	Ø.9163892E+Ø4				
SWEEP ANGLE (DEG.)	47.178				
STRIP WIDTH AT LEADING EDGE	2.Ø83				
STRIP WIDTH AT TRAILING EDGE	1.853				

STREAMLINE ID = 60

BASIC TO STREAMLINE COORDINATE SYSTEM TRANSFORMATION

0.617	0.236	-0.751
-0.527	0.833	-0.171
0.585	0.501	0.638

OSCILLATORY RELATIVE INFLOW INFORMATION

(SEMI-CHORD, AND UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY FOR THIS STREAMLINE HAVE BEEN USED TO NON-DIMENSIONALIZE INDICATED VARIABLES IN THE FOLLOWING TABLE)

EXCITATION FREQUENCY		OSCILLATORY VELOCITY (NON-DIM.)		REDUCED FREQUENCY	INTER-BLADE PHASE ANGLE
(PER REV)	(CYCLES/TIME)	(REAL)	(IMAG.)	(NON-DIM.)	(DEG.)
1	133.330	-0.68355E-02	-0.33219E-01	0.129	-45.000

STREAMLINE ID = 6Ø

1 PER REV OSCILLATORY AIRLOADS

(** IN STREAMLINE COORDINATE SYSTEM **)

GRID POINT ID	DISTANCE FROM L.E. ALONG CHORD, NON-DIM. BY SEMI-CHORD	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)
18	Ø.ØØØ	-Ø.63556E+ØØ	-Ø.43Ø98E+ØØ
21	Ø.33Ø	-Ø.94256E+ØØ	-Ø.69362E+ØØ
33	Ø.99Ø	-Ø.55159E+ØØ	-Ø.48181E+ØØ
44	1.578	-Ø.2Ø773E+ØØ	-Ø.22854E+ØØ
54	2.ØØØ	-Ø.37971E-Ø1	-Ø.5837ØE-Ø1

(** IN GRID POINT DISPLACEMENT COORDINATE SYSTEMS **)

GRID POINT ID	DISP. C.S. ID	LOAD IN T1-DIR. (REAL)	LOAD IN T1-DIR. (IMAG.)	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)	LOAD IN T3-DIR. (REAL)	LOAD IN T3-DIR. (IMAG.)
18	Ø	Ø.33473E+ØØ	Ø.22698E+ØØ	-Ø.52918E+ØØ	-Ø.35884E+ØØ	Ø.1Ø889E+ØØ	Ø.73839E-Ø1
21	Ø	Ø.49642E+ØØ	Ø.36531E+ØØ	-Ø.7848ØE+ØØ	-Ø.57752E+ØØ	Ø.16149E+ØØ	Ø.11884E+ØØ
33	Ø	Ø.29Ø5ØE+ØØ	Ø.25376E+ØØ	-Ø.45926E+ØØ	-Ø.4Ø117E+ØØ	Ø.945Ø4E-Ø1	Ø.82549E-Ø1
44	Ø	Ø.1Ø941E+ØØ	Ø.12Ø36E+ØØ	-Ø.17296E+ØØ	-Ø.19Ø28E+ØØ	Ø.35591E-Ø1	Ø.39155E-Ø1
54	Ø	Ø.19998E-Ø1	Ø.3Ø742E-Ø1	-Ø.31615E-Ø1	-Ø.486ØØE-Ø1	Ø.65Ø55E-Ø2	Ø.1ØØØ1E-Ø1

STREAMLINE ID = 7Ø

STREAMLINE COUNT FROM BLADE ROOT	7				
OSCILLATORY AIRLOADS COMPUTED AT GRID POINTS WITH ID'S	1	13	14	15	27
STAGGER ANGLE (DEG.)	31.Ø23				
CHORD	1.8Ø5				
RATE OF CHANGE OF CHORD ALONG SPANWISE REFERENCE LINE	-Ø.57Ø				
BLADE SPACING	9.716				
MACH NO. BASED ON UNIFORM PART OF RELATIVE INFLOW VELOCITY	Ø.834				
INFLOW DENSITY	Ø.9179ØØØE-Ø7				
UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY	Ø.1Ø95261E+Ø5				
SWEEP ANGLE (DEG.)	4Ø.Ø74				
STRIP WIDTH AT LEADING EDGE	Ø.866				
STRIP WIDTH AT TRAILING EDGE	Ø.997				

STREAMLINE ID = 7Ø

BASIC TO STREAMLINE COORDINATE SYSTEM TRANSFORMATION

Ø.656	Ø.3Ø1	-Ø.692
-Ø.564	Ø.8Ø5	-Ø.184
Ø.5Ø2	Ø.511	Ø.698

OSCILLATORY RELATIVE INFLOW INFORMATION

(SEMI-CHORD, AND UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY FOR THIS STREAMLINE HAVE BEEN USED TO NON-DIMENSIONALIZE INDICATED VARIABLES IN THE FOLLOWING TABLE)

EXCITATION FREQUENCY		OSCILLATORY VELOCITY (NON-DIM.)		REDUCED FREQUENCY	INTER-BLADE PHASE ANGLE
(PER REV)	(CYCLES/TIME)	(REAL)	(IMAG.)	(NON-DIM.)	(DEG.)
1	133.33Ø	-Ø.6137ØE-Ø2	-Ø.2688ØE-Ø1	Ø.Ø69	-45.ØØØ

STREAMLINE ID = 7Ø

1 PER REV OSCILLATORY AIRLOADS

(** IN STREAMLINE COORDINATE SYSTEM **)

GRID POINT ID	DISTANCE FROM L.E. ALONG CHORD, NON-DIM. BY SEMI-CHORD	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)
1	Ø.ØØØ	-Ø.46397E+ØØ	-Ø.27832E+ØØ
13	Ø.7Ø2	-Ø.3468ØE+ØØ	-Ø.23337E+ØØ
14	Ø.958	-Ø.1Ø912E+ØØ	-Ø.86913E-Ø1
15	1.215	-Ø.13763E+ØØ	-Ø.12886E+ØØ
27	2.ØØØ	-Ø.55798E-Ø1	-Ø.66236E-Ø1

(** IN GRID POINT DISPLACEMENT COORDINATE SYSTEMS **)

GRID POINT ID	DISP. C.S. ID	LOAD IN T1-DIR. (REAL)	LOAD IN T1-DIR. (IMAG.)	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)	LOAD IN T3-DIR. (REAL)	LOAD IN T3-DIR. (IMAG.)
1	Ø	Ø.26146E+ØØ	Ø.15684E+ØØ	-Ø.37361E+ØØ	-Ø.22412E+ØØ	Ø.853Ø1E-Ø1	Ø.51169E-Ø1
13	Ø	Ø.19543E+ØØ	Ø.13151E+ØØ	-Ø.27926E+ØØ	-Ø.18792E+ØØ	Ø.63758E-Ø1	Ø.429Ø5E-Ø1
14	Ø	Ø.61491E-Ø1	Ø.48978E-Ø1	-Ø.87866E-Ø1	-Ø.69986E-Ø1	Ø.2ØØ61E-Ø1	Ø.15979E-Ø1
15	Ø	Ø.7756ØE-Ø1	Ø.72615E-Ø1	-Ø.11Ø83E+ØØ	-Ø.1Ø376E+ØØ	Ø.253Ø4E-Ø1	Ø.2369ØE-Ø1
27	Ø	Ø.31443E-Ø1	Ø.37326E-Ø1	-Ø.44931E-Ø1	-Ø.53336E-Ø1	Ø.1Ø258E-Ø1	Ø.12177E-Ø1

```
*** USER INFORMATION MESSAGE ---
      CASE CONTROL CARDS ARE WRITTEN TO UNIT 7 AND BULK DATA CARDS ARE WRITTEN TO UNIT 8.
```

Case Control Data written to UNIT 7

```
$
$ NOTE ---
$   THE FOLLOWING DATA IS FOR
$   HUBTYP =  Ø     ( Ø = RIGID, 1 = FLEXIBLE )
$   FLOTYP =  Ø     ( Ø = UNIFORM, 1 = NON-UNIFORM )
$
FREQUENCY  =  1      $  SID OF FREQ BULK DATA CARD
$
   SUBCASE 1
     LABEL = K = Ø MODES, OSCILLATORY AIRLOADS PRESENT
     DLOAD = 1ØØØ
$
```

Bulk Data written to UNIT 8

```
AERO*    Ø                  Ø.91639E+Ø4    Ø.28149E+Ø1    Ø.9179ØE-Ø7    *AERO
*AERO
PARAM    CYCIO          -1
PARAM    IREF           6Ø
PARAM    MAXMACH     Ø.95Ø
PARAM    MINMACH     1.Ø1Ø
PARAM    NSEGS           8
PARAM    RPS        133.33
PARAM*   Q                   Ø.3854121E+Ø1                                *PARAMQ
*PARAMQ
PARAM*   BOV                 Ø.153589ØE-Ø3                                *PARAMB
*PARAMB
STREAML1       1Ø      175     177     163     166     156
STREAML2       1Ø        5    7.79   4.Ø32   Ø.322   2.Ø85   Ø.786.9179- 7+2   1Ø
+2     1Ø 1Ø316.6   -14.88
STREAML1       2Ø      138     14Ø     129     131     121
STREAML2       2Ø        5   17.14   4.675   Ø.1Ø8   3.5Ø8   Ø.827.9179- 7+2   2Ø
+2     2Ø 1Ø859.5   -12.13
STREAML1       3Ø       99     1Ø1     1Ø3     1Ø5     111
STREAML2       3Ø        5   18.27   4.876  -Ø.178   4.955   Ø.877.9179- 7+2   3Ø
+2     3Ø 11513.1     6.97
STREAML1       4Ø       64      75      77      92     1Ø8
STREAML2       4Ø        5   18.5Ø   4.529  -Ø.312   6.339   Ø.826.9179- 7+2   4Ø
+2     4Ø 1Ø848.5    26.Ø4
STREAML1       5Ø       37      49      6Ø      7Ø      82
STREAML2       5Ø        5   21.1Ø   3.799  -Ø.4Ø8   7.7Ø3   Ø.742.9179- 7+2   5Ø
+2     5Ø  9745.6    4Ø.Ø2
STREAML1       6Ø       18      21      33      44      54
STREAML2       6Ø        5   24.78   2.815  -Ø.57Ø   8.894   Ø.698.9179- 7+2   6Ø
+2     6Ø  9163.9    47.18
STREAML1       7Ø        1      13      14      15      27
STREAML2       7Ø        5   31.Ø2   1.8Ø5  -Ø.57Ø   9.716   Ø.834.9179- 7+2   7Ø
+2     7Ø 1Ø952.6    4Ø.Ø7
FREQ     1           133.3
MKAERO2  -45.ØØØ     Ø.129
PARAM    KMAX            Ø
PARAM    KMIN            Ø
RLOAD1   1ØØØ     11             12         13
TABLED1*13
*TB13A                                                                    *TB13A
*TB13B   Ø.Ø                 Ø.Ø               133.19667   Ø.Ø            *TB13B
*TB13C          133.19667    1.Ø               133.46333   1.Ø            *TB13C
*TB13D          133.46333    Ø.Ø        1.ØE1Ø             Ø.Ø            *TB13D
*TB13E   ENDT                                                             *TB13E
```

```
DAREA*   11        175    1  Ø.16697867E+ØØ
DPHASE*  12        175    1           38.3Ø
DAREA*   11        175    2  Ø.11229591E+Ø1
DPHASE*  12        175    2         -141.7Ø
DAREA*   11        175    3  Ø.1142968ØE+ØØ
DPHASE*  12        175    3         -141.7Ø
DAREA*   11        177    1  Ø.15455769E+ØØ
DPHASE*  12        177    1           47.47
DAREA*   11        177    2  Ø.1Ø394259E+Ø1
DPHASE*  12        177    2         -132.53
DAREA*   11        177    3  Ø.1Ø579464E+ØØ
DPHASE*  12        177    3         -132.53
DAREA*   11        163    1  Ø.91613639E-Ø1
DPHASE*  12        163    1           62.64
DAREA*   11        163    2  Ø.61611682E+ØØ
DPHASE*  12        163    2         -117.36
DAREA*   11        163    3  Ø.627Ø948ØE-Ø1
DPHASE*  12        163    3         -117.36
DAREA*   11        166    1  Ø.68733418E-Ø1
DPHASE*  12        166    1           73.66
DAREA*   11        166    2  Ø.46224357E+ØØ
DPHASE*  12        166    2         -1Ø6.34
DAREA*   11        166    3  Ø.47Ø47983E-Ø1
DPHASE*  12        166    3         -1Ø6.34
DAREA*   11        156    1  Ø.21958183E-Ø1
DPHASE*  12        156    1           84.65
DAREA*   11        156    2  Ø.1476724ØE+ØØ
DPHASE*  12        156    2          -95.35
DAREA*   11        156    3  Ø.15Ø3Ø363E-Ø1
DPHASE*  12        156    3          -95.35
DAREA*   11        138    1  Ø.57418266E+ØØ
DPHASE*  12        138    1           16.2Ø
DAREA*   11        138    2  Ø.195ØØ249E+Ø1
DPHASE*  12        138    2         -163.8Ø
DAREA*   11        138    3  Ø.2Ø845945E+ØØ
DPHASE*  12        138    3         -163.8Ø
DAREA*   11        14Ø    1  Ø.6Ø32377ØE+ØØ
DPHASE*  12        14Ø    1           29.39
DAREA*   11        14Ø    2  Ø.2Ø487Ø1ØE+Ø1
DPHASE*  12        14Ø    2         -15Ø.61
DAREA*   11        14Ø    3  Ø.219ØØ8Ø1E+ØØ
DPHASE*  12        14Ø    3         -15Ø.61
```

(Similar DAREA and DPHASE cards are generated for all grid points on STREAML3 cards)

6.6 INPUT FOR NON-UNIFORM INFLOW EXAMPLE

OSCILLATORY AIRLOADS ON BLADES OF SR-3 ADVANCED TURBOPROP
EXAMPLE 2 , NON-UNIFORM INFLOW

```
FLOTYP   NUNIFORM
NLINES   7
NSEGS    8
RPS      133.33
SSOUND   13128.
IREF     60
NASOUT   YES
MXMACH   .95
$
TNLCID   66
CORD2R   66      0       0.0     0.0     0.0     -.0349  0.0     .9994   +C66
+C66     .9994   0.0     .0349
$
PREVLIST  1      2       3
$
STREAML310       175     177     163     166     156
STREAML320       138     140     129     131     121
STREAML330       99      101     103     105     111
STREAML340       64      75      77      92      108
STREAML350       37      49      60      70      82
STREAML360       18      21      33      44      54
STREAML370       1       13      14      15      27
$
STREAML410       9.179E-8 1      3
STREAML510       1       10476.
STREAML510       2       10476.
STREAML510       3       10476.
$
STREAML420       9.179E-8 1      3
STREAML520       1       10476.
STREAML520       2       10476.
STREAML520       3       10476.
$
STREAML430       9.179E-8 1      3
STREAML530       1       10476.
STREAML530       2       10476.
STREAML530       3       10476.
```

```
$
STREAML440      9.179E-8   1      3
STREAML540      1          10476.
STREAML540      2          10476.
STREAML540      3          10476.
$
STREAML450      9.179E-8   1      3
STREAML550      1          10476.
STREAML550      2          10476.
STREAML550      3          10476.
$
STREAML460      9.179E-8   1      3
STREAML560      1          10476.
STREAML560      2          10476.
STREAML560      3          10476.
$
STREAML470      9.179E-8   2      8
STREAML570      1          11524.
STREAML570      2          11217.
STREAML570      3          10476.
STREAML570      4          9735.
STREAML570      5          9428.
STREAML570      6          9735.
STREAML570      7          10476.
STREAML570      8          11217.
$
CORD2R  77      0       .0      .0      .0      .0      .0      1.      +C2R
+C2R    10.     -0.618  .0
GRDSET          77
GRID            1               1.808   1.839   12.250
GRID            3               2.376   2.347   12.250
GRID            4               2.625   2.558   12.250
GRID            5               2.877   2.765   12.250
GRID            6               3.134   2.966   12.250
   .
   .
   .
```

All GRID data is identical to that in Example 1

6.7 OUTPUT FROM NON-UNIFORM INFLOW EXAMPLE

AIRLOADS

A PROGRAM TO COMPUTE OSCILLATORY AIRLOADS IMPOSED ON BLADES OF TURBOSYSTEMS IN SPATIALLY NON-UNIFORM INFLOW FIELDS

OSCILLATORY AIRLOADS ON BLADES OF SR-3 ADVANCED TURBOPROP

EXAMPLE 2 , NON-UNIFORM INFLOW

I N P U T   D A T A   E C H O

```
              FIELDS   ****1***----2---****3***----4---****5***----6---****7***----8---****9***---10---

CARD          COLUMN   0000000001111111111222222222233333333334444444444555555555566666666667777777778
COUNT          NOS.    1234567890123456789012345678901234567890123456789012345678901234567890123456789 0

  1                              OSCILLATORY AIRLOADS ON BLADES OF SR-3 ADVANCED TURBOPROP
  2                                        EXAMPLE 2 , NON-UNIFORM INFLOW
  3                    FLOTYP   NUNIFORM
  4                    NLINES   7
  5                    NSEGS    8
  6                    RPS      133.33
  7                    SSOUND   13128.
  8                    IREF     60
  9                    NASOUT   YES
 10                    MXMACH   .95
 11                    $
 12                    TNLCID   66
 13                    CORD2R   66      0       0.0     0.0     0.0     -.0349  0.0     .9994   +C66
 14                    +C66     .9994   0.0     .0349
 15                    $
 16                    PREVLIST 1       2       3
 17                    $
 18                    STREAML310       175     177     163     166     156
 19                    STREAML320       138     140     129     131     121
 20                    STREAML330       99      101     103     105     111
 21                    STREAML340       64      75      77      92      108
 22                    STREAML350       37      49      60      70      82
 23                    STREAML360       18      21      33      44      54
 24                    STREAML370       1       13      14      15      27
 25                    $
 26                    STREAML410       9.179E-8 1      3
 27                    STREAML510       1       10476.
 28                    STREAML510       2       10476.
 29                    STREAML510       3       10476.
 30                    $
 31                    STREAML420       9.179E-8 1      3
 32                    STREAML520       1       10476.
 33                    STREAML520       2       10476.
 34                    STREAML520       3       10476.
 35                    $
 36                    STREAML430       9.179E-8 1      3
 37                    STREAML530       1       10476.
 38                    STREAML530       2       10476.
 39                    STREAML530       3       10476.
```

```
                                    I N P U T   D A T A   E C H O
          FIELDS  ****1***----2---****3***----4---****5***----6---****7***----8---****9***---10---
 CARD     COLUMN  00000000011111111112222222222333333333344444444445555555555666666666677777777778
 COUNT     NOS.   12345678901234567890123456789012345678901234567890123456789012345678901234567890
   40             $
   41             STREAML440      9.179E-8  1       3
   42             STREAML540      1         10476.
   43             STREAML540      2         10476.
   44             STREAML540      3         10476.
   45             $
   46             STREAML450      9.179E-8  1       3
   47             STREAML550      1         10476.
   48             STREAML550      2         10476.
   49             STREAML550      3         10476.
   50             $
   51             STREAML460      9.179E-8  1       3
   52             STREAML560      1         10476.
   53             STREAML560      2         10476.
   54             STREAML560      3         10476.
   55             $
   56             STREAML470      9.179E-8  2       8
   57             STREAML570      1         11524.
   58             STREAML570      2         11217.
   59             STREAML570      3         10476.
   60             STREAML570      4         9735.
   61             STREAML570      5         9428.
   62             STREAML570      6         9735.
   63             STREAML570      7         10476.
   64             STREAML570      8         11217.
   65             $
   66             CORD2R  77      0       .0      .0      .0      .0      .0      1.      +C2R
   67             +C2R    10.     -0.618  .0
   68             GRDSET          77
   69             GRID            1
   70             GRID            3               1.808   1.839   12.250
   71             GRID            4               2.376   2.347   12.250
   72             GRID            5               2.625   2.558   12.250
   73             GRID            6               2.877   2.765   12.250
   74             GRID            7               3.134   2.966   12.250
   75             GRID            8               1.556   1.589   12.033
   76             GRID            9               1.304   1.339   11.817
   77             GRID            10              1.052   1.088   11.600
   78             GRID            12              1.293   1.308   11.600
                                                  1.791   1.730   11.600
```

(GRID data identical to that in Example 1)

```
                                   I N P U T   D A T A   E C H O

            FIELDS  ****1***----2---****3***----4---****5***----6---****7***----8---****9***---10---

CARD        COLUMN  00000000011111111112222222222333333333344444444445555555555666666666677777777778
COUNT        NOS.   12345678901234567890123456789012345678901234567890123456789012345678901234567890

 274                GRID          160            -0.917  -0.229   3.180

                             *** NO ERRORS FOUND -- EXECUTION CONTINUING ***
```

```
                    S U M M A R Y   O F   I N P U T   D A T A

NUMBER OF STREAMLINES ........................... (NLINES ) ......       7
TYPE OF FLOW .................................... (FLOTYP ) ......  NON-UNIFORM
NUMBER OF BLADE SEGMENTS ........................ (NSEGS  ) ......       8
ROTATIONAL SPEED ................................ (RPS    ) ......    133.3300
SPEED OF SOUND .................................. (SSOUND ) ......  13128.0000
UPPER MACH NUMBER LIMIT FOR SUBSONIC FLOW ....... (MXMACH ) ......      0.9500
LOWER MACH NUMBER LIMIT FOR SUPERSONIC FLOW ..... (DEFAULT) ......      1.0100
REFERENCE STREAMLINE ID ......................... (IREF   ) ......      60
TYPE OF HUB ..................................... (DEFAULT) ......  RIGID
NASTRAN-TYPE OUTPUT DESIRED ..................... (NASOUT ) ......  YES
TUNNEL COORDINATE SYSTEM ID ..................... (TNLCID ) ......      66

NUMBER OF GRID POINTS ...........................................      35
NO. OF RECT. COORDINATE SYSTEMS DEFINED .........................       2
```

```
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      2 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     10
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      3 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     10
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      2 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     20
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      3 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     20
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      2 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     30
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      3 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     30
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      2 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     40
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      3 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     40
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      2 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     50
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      3 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     50
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      2 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     60
**WARNING***SUBROUTINE GNCASE, DO 150 LOOP,
      3 PER REV EXCITATION FREQUENCY IS NOT ADMISSIBLE ON STREAMLINE ID     60
```

STREAMLINE ID = 10

STREAMLINE COUNT FROM BLADE ROOT	1				
OSCILLATORY AIRLOADS COMPUTED AT GRID POINTS WITH ID'S	175	177	163	166	156
STAGGER ANGLE (DEG.)	7.792				
CHORD	4.032				
RATE OF CHANGE OF CHORD ALONG SPANWISE REFERENCE LINE	0.322				
BLADE SPACING	2.085				
MACH NO. BASED ON UNIFORM PART OF RELATIVE INFLOW VELOCITY	0.786				
INFLOW DENSITY	0.9179000E-07				
UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY	0.1031659E+05				
SWEEP ANGLE (DEG.)	-14.878				
STRIP WIDTH AT LEADING EDGE	0.961				
STRIP WIDTH AT TRAILING EDGE	0.917				

STREAMLINE ID = 10

BASIC TO STREAMLINE COORDINATE SYSTEM TRANSFORMATION

0.958	0.116	0.264
-0.144	0.971	0.099
-0.245	-0.133	0.947

OSCILLATORY RELATIVE INFLOW INFORMATION

(SEMI-CHORD, AND UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY FOR THIS STREAMLINE HAVE BEEN USED TO NON-DIMENSIONALIZE INDICATED VARIABLES IN THE FOLLOWING TABLE)

EXCITATION FREQUENCY		OSCILLATORY VELOCITY (NON-DIM.)		REDUCED FREQUENCY	INTER-BLADE PHASE ANGLE
(PER REV)	(CYCLES/TIME)	(REAL)	(IMAG.)	(NON-DIM.)	(DEG.)
1	133.330	0.35036E-02	-0.34422E-01	0.164	-45.000
2	266.660	0.00000E+00	0.00000E+00	0.327	-90.000
3	399.990	0.00000E+00	0.00000E+00	0.491	-135.000

STREAMLINE ID = 1Ø

1 PER REV OSCILLATORY AIRLOADS

(** IN STREAMLINE COORDINATE SYSTEM **)

GRID POINT ID	DISTANCE FROM L.E. ALONG CHORD, NON-DIM. BY SEMI-CHORD	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)
175	Ø.ØØØ	-Ø.9Ø728E+ØØ	-Ø.71657E+ØØ
177	Ø.52Ø	-Ø.72336E+ØØ	-Ø.78862E+ØØ
163	Ø.942	-Ø.29155E+ØØ	-Ø.56334E+ØØ
166	1.471	-Ø.13386E+ØØ	-Ø.45668E+ØØ
156	2.ØØØ	-Ø.14169E-Ø1	-Ø.15137E+ØØ

(** IN GRID POINT DISPLACEMENT COORDINATE SYSTEMS **)

GRID POINT ID	DISP. C.S. ID	LOAD IN T1-DIR. (REAL)	LOAD IN T1-DIR. (IMAG.)	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)	LOAD IN T3-DIR. (REAL)	LOAD IN T3-DIR. (IMAG.)
175	Ø	Ø.131Ø4E+ØØ	Ø.1Ø349E+ØØ	-Ø.88126E+ØØ	-Ø.696Ø1E+ØØ	-Ø.89696E-Ø1	-Ø.7Ø841E-Ø1
177	Ø	Ø.1Ø447E+ØØ	Ø.1139ØE+ØØ	-Ø.7Ø261E+ØØ	-Ø.766ØØE+ØØ	-Ø.71513E-Ø1	-Ø.77965E-Ø1
163	Ø	Ø.421Ø8E-Ø1	Ø.81364E-Ø1	-Ø.28318E+ØØ	-Ø.54718E+ØØ	-Ø.28823E-Ø1	-Ø.55693E-Ø1
166	Ø	Ø.19333E-Ø1	Ø.65959E-Ø1	-Ø.13ØØ2E+ØØ	-Ø.44358E+ØØ	-Ø.13233E-Ø1	-Ø.45149E-Ø1
156	Ø	Ø.2Ø465E-Ø2	Ø.21863E-Ø1	-Ø.13763E-Ø1	-Ø.147Ø3E+ØØ	-Ø.14ØØ8E-Ø2	-Ø.14965E-Ø1

(Similar output for Streamline ID's 20 through 50 appears on pages 13-34)

STREAMLINE ID = 60

STREAMLINE COUNT FROM BLADE ROOT	6				
OSCILLATORY AIRLOADS COMPUTED AT GRID POINTS WITH ID'S	18	21	33	44	54
STAGGER ANGLE (DEG.)	24.776				
CHORD	2.815				
RATE OF CHANGE OF CHORD ALONG SPANWISE REFERENCE LINE	-0.570				
BLADE SPACING	8.894				
MACH NO. BASED ON UNIFORM PART OF RELATIVE INFLOW VELOCITY	0.698				
INFLOW DENSITY	0.9179000E-07				
UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY	0.9163892E+04				
SWEEP ANGLE (DEG.)	47.178				
STRIP WIDTH AT LEADING EDGE	2.083				
STRIP WIDTH AT TRAILING EDGE	1.853				

STREAMLINE ID = 60

BASIC TO STREAMLINE COORDINATE SYSTEM TRANSFORMATION

0.617	0.236	-0.751
-0.527	0.833	-0.171
0.585	0.501	0.638

OSCILLATORY RELATIVE INFLOW INFORMATION

(SEMI-CHORD, AND UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY FOR THIS STREAMLINE HAVE BEEN USED TO NON-DIMENSIONALIZE INDICATED VARIABLES IN THE FOLLOWING TABLE)

EXCITATION FREQUENCY		OSCILLATORY VELOCITY (NON-DIM.)		REDUCED FREQUENCY	INTER-BLADE PHASE ANGLE
(PER REV)	(CYCLES/TIME)	(REAL)	(IMAG.)	(NON-DIM.)	(DEG.)
1	133.330	-0.68355E-02	-0.33219E-01	0.129	-45.000
2	266.660	0.00000E+00	0.00000E+00	0.257	-90.000
3	399.990	0.00000E+00	0.00000E+00	0.386	-135.000

STREAMLINE ID = 60

1 PER REV OSCILLATORY AIRLOADS

(** IN STREAMLINE COORDINATE SYSTEM **)

GRID POINT ID	DISTANCE FROM L.E. ALONG CHORD, NON-DIM. BY SEMI-CHORD	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)
18	0.000	-0.63557E+00	-0.43098E+00
21	0.330	-0.94257E+00	-0.69362E+00
33	0.990	-0.55159E+00	-0.48182E+00
44	1.578	-0.20774E+00	-0.22854E+00
54	2.000	-0.37971E-01	-0.58371E-01

(** IN GRID POINT DISPLACEMENT COORDINATE SYSTEMS **)

GRID POINT ID	DISP. C.S. ID	LOAD IN T1-DIR. (REAL)	LOAD IN T1-DIR. (IMAG.)	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)	LOAD IN T3-DIR. (REAL)	LOAD IN T3-DIR. (IMAG.)
18	0	0.33473E+00	0.22698E+00	-0.52918E+00	-0.35884E+00	0.10889E+00	0.73839E-01
21	0	0.49642E+00	0.36531E+00	-0.78480E+00	-0.57753E+00	0.16149E+00	0.11884E+00
33	0	0.29051E+00	0.25376E+00	-0.45927E+00	-0.40117E+00	0.94504E-01	0.82549E-01
44	0	0.10941E+00	0.12036E+00	-0.17296E+00	-0.19029E+00	0.35591E-01	0.39155E-01
54	0	0.19998E-01	0.30742E-01	-0.31615E-01	-0.48601E-01	0.65056E-02	0.10001E-01

STREAMLINE ID = 7Ø

STREAMLINE COUNT FROM BLADE ROOT	7				
OSCILLATORY AIRLOADS COMPUTED AT GRID POINTS WITH ID'S	1	13	14	15	27
STAGGER ANGLE (DEG.)	31.Ø23				
CHORD	1.8Ø5				
RATE OF CHANGE OF CHORD ALONG SPANWISE REFERENCE LINE	-Ø.57Ø				
BLADE SPACING	9.716				
MACH NO. BASED ON UNIFORM PART OF RELATIVE INFLOW VELOCITY	Ø.834				
INFLOW DENSITY	Ø.9179ØØØE-Ø7				
UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY	Ø.1Ø95261E+Ø5				
SWEEP ANGLE (DEG.)	4Ø.Ø74				
STRIP WIDTH AT LEADING EDGE	Ø.866				
STRIP WIDTH AT TRAILING EDGE	Ø.997				

STREAMLINE ID = 7Ø

BASIC TO STREAMLINE COORDINATE SYSTEM TRANSFORMATION

Ø.656	Ø.3Ø1	-Ø.692
-Ø.564	Ø.8Ø5	-Ø.184
Ø.5Ø2	Ø.511	Ø.698

OSCILLATORY RELATIVE INFLOW INFORMATION

(SEMI-CHORD, AND UNIFORM PART OF CASCADE RELATIVE INFLOW VELOCITY FOR THIS STREAMLINE HAVE BEEN USED TO NON-DIMENSIONALIZE INDICATED VARIABLES IN THE FOLLOWING TABLE)

EXCITATION FREQUENCY (PER REV)	EXCITATION FREQUENCY (CYCLES/TIME)	OSCILLATORY VELOCITY (NON-DIM.) (REAL)	OSCILLATORY VELOCITY (NON-DIM.) (IMAG.)	REDUCED FREQUENCY (NON-DIM.)	INTER-BLADE PHASE ANGLE (DEG.)
1	133.33Ø	-Ø.6444ØE-Ø2	-Ø.25535E-Ø1	Ø.Ø69	-45.ØØØ
2	266.66Ø	-Ø.53886E-Ø1	Ø.71219E-Ø8	Ø.138	-9Ø.ØØØ
3	399.99Ø	-Ø.3Ø696E-Ø3	-Ø.13445E-Ø2	Ø.2Ø7	-135.ØØØ

STREAMLINE ID = 7Ø

1 PER REV OSCILLATORY AIRLOADS

(** IN STREAMLINE COORDINATE SYSTEM **)

GRID POINT ID	DISTANCE FROM L.E. ALONG CHORD, NON-DIM. BY SEMI-CHORD	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)
1	Ø.ØØØ	-Ø.44911E+ØØ	-Ø.25571E+ØØ
13	Ø.7Ø2	-Ø.33624E+ØØ	-Ø.21533E+ØØ
14	Ø.958	-Ø.1Ø6Ø9E+ØØ	-Ø.8Ø628E-Ø1
15	1.215	-Ø.13423E+ØØ	-Ø.12ØØ6E+ØØ
27	2.ØØØ	-Ø.54722E-Ø1	-Ø.62Ø41E-Ø1

(** IN GRID POINT DISPLACEMENT COORDINATE SYSTEMS **)

GRID POINT ID	DISP. C.S. ID	LOAD IN T1-DIR. (REAL)	LOAD IN T1-DIR. (IMAG.)	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)	LOAD IN T3-DIR. (REAL)	LOAD IN T3-DIR. (IMAG.)
1	Ø	Ø.253Ø8E+ØØ	Ø.1441ØE+ØØ	-Ø.36164E+ØØ	-Ø.2Ø591E+ØØ	Ø.82568E-Ø1	Ø.47Ø12E-Ø1
13	Ø	Ø.18948E+ØØ	Ø.12134E+ØØ	-Ø.27Ø75E+ØØ	-Ø.17339E+ØØ	Ø.61817E-Ø1	Ø.39588E-Ø1
14	Ø	Ø.59783E-Ø1	Ø.45436E-Ø1	-Ø.85427E-Ø1	-Ø.64925E-Ø1	Ø.195Ø4E-Ø1	Ø.14823E-Ø1
15	Ø	Ø.75641E-Ø1	Ø.6766ØE-Ø1	-Ø.1Ø8Ø9E+ØØ	-Ø.96681E-Ø1	Ø.24678E-Ø1	Ø.22Ø74E-Ø1
27	Ø	Ø.3Ø837E-Ø1	Ø.34962E-Ø1	-Ø.44Ø64E-Ø1	-Ø.49958E-Ø1	Ø.1ØØ6ØE-Ø1	Ø.114Ø6E-Ø1

STREAMLINE ID = 70

2 PER REV OSCILLATORY AIRLOADS

(** IN STREAMLINE COORDINATE SYSTEM **)

GRID POINT ID	DISTANCE FROM L.E. ALONG CHORD, NON-DIM. BY SEMI-CHORD	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)
1	0.000	-0.32127E+00	0.80519E+00
13	0.702	-0.35720E+00	0.66850E+00
14	0.958	-0.17895E+00	0.23522E+00
15	1.215	-0.31914E+00	0.30585E+00
27	2.000	-0.18828E+00	0.12379E+00

(** IN GRID POINT DISPLACEMENT COORDINATE SYSTEMS **)

GRID POINT ID	DISP. C.S. ID	LOAD IN T1-DIR. (REAL)	LOAD IN T1-DIR. (IMAG.)	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)	LOAD IN T3-DIR. (REAL)	LOAD IN T3-DIR. (IMAG.)
1	0	0.18104E+00	-0.45374E+00	-0.25870E+00	0.64837E+00	0.59064E-01	-0.14803E+00
13	0	0.20129E+00	-0.37672E+00	-0.28763E+00	0.53831E+00	0.65671E-01	-0.12290E+00
14	0	0.10084E+00	-0.13255E+00	-0.14410E+00	0.18941E+00	0.32900E-01	-0.43246E-01
15	0	0.17984E+00	-0.17235E+00	-0.25698E+00	0.24628E+00	0.58673E-01	-0.56230E-01
27	0	0.10610E+00	-0.69761E-01	-0.15161E+00	0.99685E-01	0.34615E-01	-0.22760E-01

STREAMLINE ID = 7Ø

3 PER REV OSCILLATORY AIRLOADS

(** IN STREAMLINE COORDINATE SYSTEM **)

GRID POINT ID	DISTANCE FROM L.E. ALONG CHORD, NON-DIM. BY SEMI-CHORD	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)
1	Ø.ØØØ	-Ø.19851E-Ø1	-Ø.72534E-Ø2
13	Ø.7Ø2	-Ø.16ØØ6E-Ø1	-Ø.78728E-Ø2
14	Ø.958	-Ø.54117E-Ø2	-Ø.38485E-Ø2
15	1.215	-Ø.68198E-Ø2	-Ø.68154E-Ø2
27	2.ØØØ	-Ø.27559E-Ø2	-Ø.42147E-Ø2

(** IN GRID POINT DISPLACEMENT COORDINATE SYSTEMS **)

GRID POINT ID	DISP. C.S. ID	LOAD IN T1-DIR. (REAL)	LOAD IN T1-DIR. (IMAG.)	LOAD IN T2-DIR. (REAL)	LOAD IN T2-DIR. (IMAG.)	LOAD IN T3-DIR. (REAL)	LOAD IN T3-DIR. (IMAG.)
1	Ø	Ø.11186E-Ø1	Ø.4Ø875E-Ø2	-Ø.15985E-Ø1	-Ø.584Ø8E-Ø2	Ø.36495E-Ø2	Ø.13335E-Ø2
13	Ø	Ø.9Ø2Ø1E-Ø2	Ø.44365E-Ø2	-Ø.12889E-Ø1	-Ø.63395E-Ø2	Ø.29428E-Ø2	Ø.14474E-Ø2
14	Ø	Ø.3Ø496E-Ø2	Ø.21687E-Ø2	-Ø.43577E-Ø2	-Ø.3Ø99ØE-Ø2	Ø.99493E-Ø3	Ø.7Ø755E-Ø3
15	Ø	Ø.38431E-Ø2	Ø.384Ø7E-Ø2	-Ø.54916E-Ø2	-Ø.54881E-Ø2	Ø.12538E-Ø2	Ø.1253ØE-Ø2
27	Ø	Ø.1553ØE-Ø2	Ø.23751E-Ø2	-Ø.22192E-Ø2	-Ø.33939E-Ø2	Ø.5Ø667E-Ø3	Ø.77487E-Ø3

```
*** USER INFORMATION MESSAGE ---
      CASE CONTROL CARDS ARE WRITTEN TO UNIT 7 AND BULK DATA CARDS ARE WRITTEN TO UNIT 8.
1
```

Case Control Data written to UNIT 7

```
$
$ NOTE ---
$   THE FOLLOWING DATA IS FOR
$   HUBTYP =  Ø     ( Ø = RIGID, 1 = FLEXIBLE )
$   FLOTYP =  1     ( Ø = UNIFORM, 1 = NON-UNIFORM )
$
FREQUENCY  =  1      $  SID OF FREQ BULK DATA CARD
$
   SUBCASE 1
     LABEL = K = Ø MODES, OSCILLATORY AIRLOADS PRESENT
     DLOAD = 1ØØØ
$
```

Bulk Data written to UNIT 8

```
AERO*   Ø              Ø.91639E+Ø4    Ø.28149E+Ø1    Ø.9179ØE-Ø7    *AERO
*AERO
PARAM   CYCIO        -1
PARAM   IREF         6Ø
PARAM   MAXMACH   Ø.95Ø
PARAM   MINMACH   1.Ø1Ø
PARAM   NSEGS         8
PARAM   RPS      133.33
PARAM*  Q               Ø.3854121E+Ø1                                  *PARAMQ
*PARAMQ
PARAM*  BOV             Ø.1535890E-Ø3                                  *PARAMB
*PARAMB
STREAML1      1Ø    175    177    163    166    156
STREAML2      1Ø      5   7.79  4.Ø32  Ø.322  2.Ø85
+2     1Ø 1Ø316.6 -14.88                              Ø.786.9179- 7+2    1Ø
STREAML1      2Ø    138    14Ø    129    131    121
STREAML2      2Ø      5  17.14  4.675  Ø.1Ø8  3.5Ø8
+2     2Ø 1Ø859.5 -12.13                              Ø.827.9179- 7+2    2Ø
STREAML1      3Ø     99    1Ø1    1Ø3    1Ø5    111
STREAML2      3Ø      5  18.27  4.876 -Ø.178  4.955
+2     3Ø 11513.1   6.97                              Ø.877.9179- 7+2    3Ø
STREAML1      4Ø     64     75     77     92    1Ø8
STREAML2      4Ø      5  18.5Ø  4.529 -Ø.312  6.339
+2     4Ø 1Ø848.5  26.Ø4                              Ø.826.9179- 7+2    4Ø
STREAML1      5Ø     37     49     6Ø     7Ø     82
STREAML2      5Ø      5  21.1Ø  3.799 -Ø.4Ø8  7.7Ø3
+2     5Ø  9745.6  4Ø.Ø2                              Ø.742.9179- 7+2    5Ø
STREAML1      6Ø     18     21     33     44     54
STREAML2      6Ø      5  24.78  2.815 -Ø.57Ø  8.894
+2     6Ø  9163.9  47.18                              Ø.698.9179- 7+2    6Ø
STREAML1      7Ø      1     13     14     15     27
STREAML2      7Ø      5  31.Ø2  1.8Ø5 -Ø.57Ø  9.716
+2     7Ø 1Ø952.6  4Ø.Ø7                              Ø.834.9179- 7+2    7Ø
FREQ    1         133.3
MKAERO2 -45.ØØØ   Ø.129
PARAM   KMAX          Ø
PARAM   KMIN          Ø
DLOAD   1ØØØ    1.Ø      1.Ø    1ØØØ1    1.Ø    1ØØØ2    1.Ø    1ØØØ3
RLOAD1  1ØØØ1   11              12       13
RLOAD1  1ØØØ2   21              22       23
RLOAD1  1ØØØ3   31              32       33
TABLED1*13
*TB13A                                                              *TB13A
*TB13B  Ø.Ø              Ø.Ø                                         *TB13B
*TB13C       133.19667   1.Ø              133.19667   Ø.Ø           *TB13C
*TB13D       133.46333   Ø.Ø              133.46333   1.Ø           *TB13D
*TB13E  ENDT                       1.ØE1Ø             Ø.Ø           *TB13E
```

DAREA*	11	175	1	Ø.16697953E+ØØ
DPHASE*	12	175	1	38.3Ø
DAREA*	11	175	2	Ø.11229649E+Ø1
DPHASE*	12	175	2	-141.7Ø
DAREA*	11	175	3	Ø.11429739E+ØØ
DPHASE*	12	175	3	-141.7Ø
DAREA*	11	177	1	Ø.15455848E+ØØ
DPHASE*	12	177	1	47.47
DAREA*	11	177	2	Ø.1Ø394313E+Ø1
DPHASE*	12	177	2	-132.53
DAREA*	11	177	3	Ø.1Ø579519E+ØØ
DPHASE*	12	177	3	-132.53
DAREA*	11	163	1	Ø.91614111E-Ø1
DPHASE*	12	163	1	62.64
DAREA*	11	163	2	Ø.61612ØØØE+ØØ
DPHASE*	12	163	2	-117.36
DAREA*	11	163	3	Ø.627Ø98Ø4E-Ø1
DPHASE*	12	163	3	-117.36
DAREA*	11	166	1	Ø.68733773E-Ø1
DPHASE*	12	166	1	73.66
DAREA*	11	166	2	Ø.46224595E+ØØ
DPHASE*	12	166	2	-1Ø6.34
DAREA*	11	166	3	Ø.47Ø48226E-Ø1
DPHASE*	12	166	3	-1Ø6.34
DAREA*	11	156	1	Ø.21958296E-Ø1
DPHASE*	12	156	1	84.65
DAREA*	11	156	2	Ø.14767316E+ØØ
DPHASE*	12	156	2	-95.35
DAREA*	11	156	3	Ø.15Ø3Ø44ØE-Ø1
DPHASE*	12	156	3	-95.35
DAREA*	11	138	1	Ø.57418563E+ØØ
DPHASE*	12	138	1	16.2Ø
DAREA*	11	138	2	Ø.195ØØ35ØE+Ø1
DPHASE*	12	138	2	-163.8Ø
DAREA*	11	138	3	Ø.2ØØ46Ø53E+ØØ
DPHASE*	12	138	3	-163.8Ø
DAREA*	11	14Ø	1	Ø.6Ø324Ø82E+ØØ
DPHASE*	12	14Ø	1	29.39
DAREA*	11	14Ø	2	Ø.2Ø487115E+Ø1
DPHASE*	12	14Ø	2	-15Ø.61
DAREA*	11	14Ø	3	Ø.219ØØ914E+ØØ
DPHASE*	12	14Ø	3	-15Ø.61
DAREA*	11	129	1	Ø.33933659E+ØØ
DPHASE*	12	129	1	55.33
DAREA*	11	129	2	Ø.11524465E+Ø1
DPHASE*	12	129	2	-124.67
DAREA*	11	129	3	Ø.12319759E+ØØ
DPHASE*	12	129	3	-124.67

```
DAREA*   11        131     1  Ø.21757445E+ØØ
DPHASE*  12        131     1           75.16
DAREA*   11        131     2  Ø.73892Ø98E+ØØ
DPHASE*  12        131     2         -1Ø4.84
DAREA*   11        131     3  Ø.78991330E-Ø1
DPHASE*  12        131     3         -1Ø4.84
DAREA*   11        121     1  Ø.68324327E-Ø1
DPHASE*  12        121     1           88.12
DAREA*   11        121     2  Ø.232Ø4139E+ØØ
DPHASE*  12        121     2          -91.88
DAREA*   11        121     3  Ø.248Ø5437E-Ø1
DPHASE*  12        121     3          -91.88
DAREA*   11         99     1  Ø.526Ø4746E+ØØ
DPHASE*  12         99     1           -7.Ø5
DAREA*   11         99     2  Ø.15372627E+Ø1
DPHASE*  12         99     2          172.95
DAREA*   11         99     3  Ø.14154861E+ØØ
DPHASE*  12         99     3          172.95
DAREA*   11        1Ø1     1  Ø.6Ø993767E+ØØ
DPHASE*  12        1Ø1     1            8.77
DAREA*   11        1Ø1     2  Ø.17824142E+Ø1
DPHASE*  12        1Ø1     2         -171.23
DAREA*   11        1Ø1     3  Ø.16412175E+ØØ
DPHASE*  12        1Ø1     3         -171.23
DAREA*   11        1Ø3     1  Ø.34Ø96279E+ØØ
DPHASE*  12        1Ø3     1           37.7Ø
DAREA*   11        1Ø3     2  Ø.99639182E+ØØ
DPHASE*  12        1Ø3     2         -142.3Ø
DAREA*   11        1Ø3     3  Ø.91746112E-Ø1
DPHASE*  12        1Ø3     3         -142.3Ø
DAREA*   11        1Ø5     1  Ø.16581313E+ØØ
DPHASE*  12        1Ø5     1           61.75
DAREA*   11        1Ø5     2  Ø.4845539ØE+ØØ
DPHASE*  12        1Ø5     2         -118.25
DAREA*   11        1Ø5     3  Ø.44616923E-Ø1
DPHASE*  12        1Ø5     3         -118.25
DAREA*   11        111     1  Ø.35667655E-Ø1
DPHASE*  12        111     1           77.85
DAREA*   11        111     2  Ø.1Ø42312ØE+ØØ
DPHASE*  12        111     2         -1Ø2.15
DAREA*   11        111     3  Ø.95974363E-Ø2
DPHASE*  12        111     3         -1Ø2.15
DAREA*   11         64     1  Ø.6Ø111218E+ØØ
DPHASE*  12         64     1            8.85
DAREA*   11         64     2  Ø.144Ø5572E+Ø1
```

DPHASE* 12	64	2	-171.15
DAREA* 11	64	3	0.54113747E-01
DPHASE* 12	64	3	8.85
DAREA* 11	75	1	0.66993981E+00
DPHASE* 12	75	1	17.25
DAREA* 11	75	2	0.16055017E+01
DPHASE* 12	75	2	-162.75
DAREA* 11	75	3	0.60309797E-01
DPHASE* 12	75	3	17.25
DAREA* 11	77	1	0.37152310E+00
DPHASE* 12	77	1	35.10
DAREA* 11	77	2	0.89035006E+00
DPHASE* 12	77	2	-144.90
DAREA* 11	77	3	0.33445516E-01
DPHASE* 12	77	3	35.10
DAREA* 11	92	1	0.20735417E+00
DPHASE* 12	92	1	53.41
DAREA* 11	92	2	0.49692145E+00
DPHASE* 12	92	2	-126.59
DAREA* 11	92	3	0.18666584E-01
DPHASE* 12	92	3	53.41
DAREA* 11	100	1	0.55394483E-01
DPHASE* 12	100	1	68.02
DAREA* 11	100	2	0.13275213E+00
DPHASE* 12	100	2	-111.98
DAREA* 11	100	3	0.49867615E-02
DPHASE* 12	100	3	68.02
DAREA* 11	37	1	0.79818315E+00
DPHASE* 12	37	1	25.97
DAREA* 11	37	2	0.14759352E+01
DPHASE* 12	37	2	-154.03
DAREA* 11	37	3	0.20008219E+00
DPHASE* 12	37	3	25.97
DAREA* 11	49	1	0.71490681E+00
DPHASE* 12	49	1	31.01
DAREA* 11	49	2	0.13219473E+01
DPHASE* 12	49	2	-148.99
DAREA* 11	49	3	0.17920714E+00
DPHASE* 12	49	3	31.01
DAREA* 11	60	1	0.27469777E+00
DPHASE* 12	60	1	40.23
DAREA* 11	60	2	0.50794869E+00
DPHASE* 12	60	2	-139.77
DAREA* 11	60	3	0.68859046E-01
DPHASE* 12	60	3	40.23
DAREA* 11	70	1	0.17440704E+00
DPHASE* 12	70	1	49.76
DAREA* 11	70	2	0.32250075E+00
DPHASE* 12	70	2	-130.24
DAREA* 11	70	3	0.43719167E-01
DPHASE* 12	70	3	49.76
DAREA* 11	82	1	0.67720691E-01
DPHASE* 12	82	1	59.47
DAREA* 11	82	2	0.12522358E+00
DPHASE* 12	82	2	-120.53
DAREA* 11	82	3	0.16975683E-01
DPHASE* 12	82	3	59.47
DAREA* 11	18	1	0.40443467E+00
DPHASE* 12	18	1	34.14
DAREA* 11	18	2	0.63937744E+00
DPHASE* 12	18	2	-145.86
DAREA* 11	18	3	0.13156589E+00
DPHASE* 12	18	3	34.14
DAREA* 11	21	1	0.61634832E+00
DPHASE* 12	21	1	36.35
DAREA* 11	21	2	0.97439522E+00
[illegible]	[illegible]	[illegible]	-147.[illegible]

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[illegible]
DAREA*   11                  21      3  0.20050313E+00
DPHASE*  12                  21      3           36.35
DAREA*   11                  33      1  0.38572877E+00
DPHASE*  12                  33      1           41.14
DAREA*   11                  33      2  0.60980498E+00
DPHASE*  12                  33      2         -138.86
DAREA*   11                  33      3  0.12548071E+00
DPHASE*  12                  33      3           41.14
DAREA*   11                  44      1  0.16265800E+00
DPHASE*  12                  44      1           47.73
DAREA*   11                  44      2  0.25714871E+00
DPHASE*  12                  44      2         -132.27
DAREA*   11                  44      3  0.52913971E-01
DPHASE*  12                  44      3           47.73
DAREA*   11                  54      1  0.36674195E-01
DPHASE*  12                  54      1           56.96
DAREA*   11                  54      2  0.57978840E-01
DPHASE*  12                  54      2         -123.04
DAREA*   11                  54      3  0.11930414E-01
DPHASE*  12                  54      3           56.96
DAREA*   11                   1      1  0.29123266E+00
DPHASE*  12                   1      1           29.66
DAREA*   11                   1      2  0.41615347E+00
DPHASE*  12                   1      2         -150.34
DAREA*   11                   1      3  0.95014074E-01
DPHASE*  12                   1      3           29.66
DAREA*   11                  13      1  0.22500203E+00
DPHASE*  12                  13      1           32.64
DAREA*   11                  13      2  0.32151399E+00
DPHASE*  12                  13      2         -147.36
DAREA*   11                  13      3  0.73406463E-01
DPHASE*  12                  13      3           32.64
DAREA*   11                  14      1  0.75089777E-01
DPHASE*  12                  14      1           37.24
DAREA*   11                  14      2  0.10729865E+00
DPHASE*  12                  14      2         -142.76
DAREA*   11                  14      3  0.24497890E-01
DPHASE*  12                  14      3           37.24
DAREA*   11                  15      1  0.10148605E+00
DPHASE*  12                  15      1           41.81
DAREA*   11                  15      2  0.14501730E+00
DPHASE*  12                  15      2         -138.19
DAREA*   11                  15      3  0.33109622E-01
DPHASE*  12                  15      3           41.81
DAREA*   11                  27      1  0.46617877E-01
DPHASE*  12                  27      1           48.59
DAREA*   11                  27      2  0.66614065E-01
DPHASE*  12                  27      2         -131.41
DAREA*   11                  27      3  0.15208989E-01
DPHASE*  12                  27      3           48.59
TABLED1*23                                                  *TB23A
*TB23A
*TB23B  0.0             0.0         266.39334  0.0          *TB23B
*TB23C        266.39334 1.0         266.92666  1.0          *TB23C
*TB23D        266.92666 0.0       1.0E10       0.0          *TB23D
*TB23E  ENDT                                                *TB23E
DAREA*   21                   1      1  0.48852849E+00
DPHASE*  22                   1      1          -68.25
DAREA*   21                   1      2  0.69807702E+00
DPHASE*  22                   1      2          111.75
DAREA*   21                   1      3  0.15938145E+00
DPHASE*  22                   1      3          -68.25
DAREA*   21                  13      1  0.42712290E+00
DPHASE*  22                  13      1          -61.88
DAREA*   21                  13      2  0.61033223E+00
[illegible]
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DAREA*   21                       13       3  0.13934799E+00
DPHASE*  22                       13       3          -61.88
DAREA*   21                       14       1  0.16655425E+00
DPHASE*  22                       14       1          -52.74
DAREA*   21                       14       2  0.23799573E+00
DPHASE*  22                       14       2          127.26
DAREA*   21                       14       3  0.54337992E-01
DPHASE*  22                       14       3          -52.74
DAREA*   21                       15       1  0.24909627E+00
DPHASE*  22                       15       1          -43.78
DAREA*   21                       15       2  0.35594317E+00
DPHASE*  22                       15       2          136.22
DAREA*   21                       15       3  0.81267161E-01
DPHASE*  22                       15       3          -43.78
DAREA*   21                       27       1  0.12697997E+00
DPHASE*  22                       27       1          -33.33
DAREA*   21                       27       2  0.18144653E+00
DPHASE*  22                       27       2          146.67
DAREA*   21                       27       3  0.41426961E-01
DPHASE*  22                       27       3          -33.33
TABLED1*33                                                    *TB33A
*TB33A
*TB33B   0.0                          0.0         399.59001   0.0      *TB33B
*TB33C          399.59001   1.0                   400.38999   1.0      *TB33C
*TB33D          400.38999   0.0           1.0E10              0.0      *TB33D
*TB33E   ENDT                                                          *TB33E
DAREA*   31                        1       1  0.11909725E-01
DPHASE*  32                        1       1           20.07
DAREA*   31                        1       2  0.17018261E-01
DPHASE*  32                        1       2         -159.93
DAREA*   31                        1       3  0.38855240E-02
DPHASE*  32                        1       3           20.07
DAREA*   31                       13       1  0.10052078E-01
DPHASE*  32                       13       1           26.19
DAREA*   31                       13       2  0.14363798E-01
DPHASE*  32                       13       2         -153.81
DAREA*   31                       13       3  0.32794703E-02
DPHASE*  32                       13       3           26.19
DAREA*   31                       14       1  0.37421373E-02
DPHASE*  32                       14       1           35.42
DAREA*   31                       14       2  0.53472829E-02
DPHASE*  32                       14       2         -144.58
DAREA*   31                       14       3  0.12208648E-02
DPHASE*  32                       14       3           35.42
DAREA*   31                       15       1  0.54332715E-02
DPHASE*  32                       15       1           44.98
DAREA*   31                       15       2  0.77638093E-02
DPHASE*  32                       15       2         -135.02
DAREA*   31                       15       3  0.17725940E-02
DPHASE*  32                       15       3           44.98
DAREA*   31                       27       1  0.28377811E-02
DPHASE*  32                       27       1           56.82
DAREA*   31                       27       2  0.40550138E-02
DPHASE*  32                       27       2         -123.18
DAREA*   31                       27       3  0.92582042E-03
DPHASE*  32                       27       3           56.82
```

APPENDIX A

AERODYNAMIC EXCITATION PARAMETERS

A .1 GENERAL

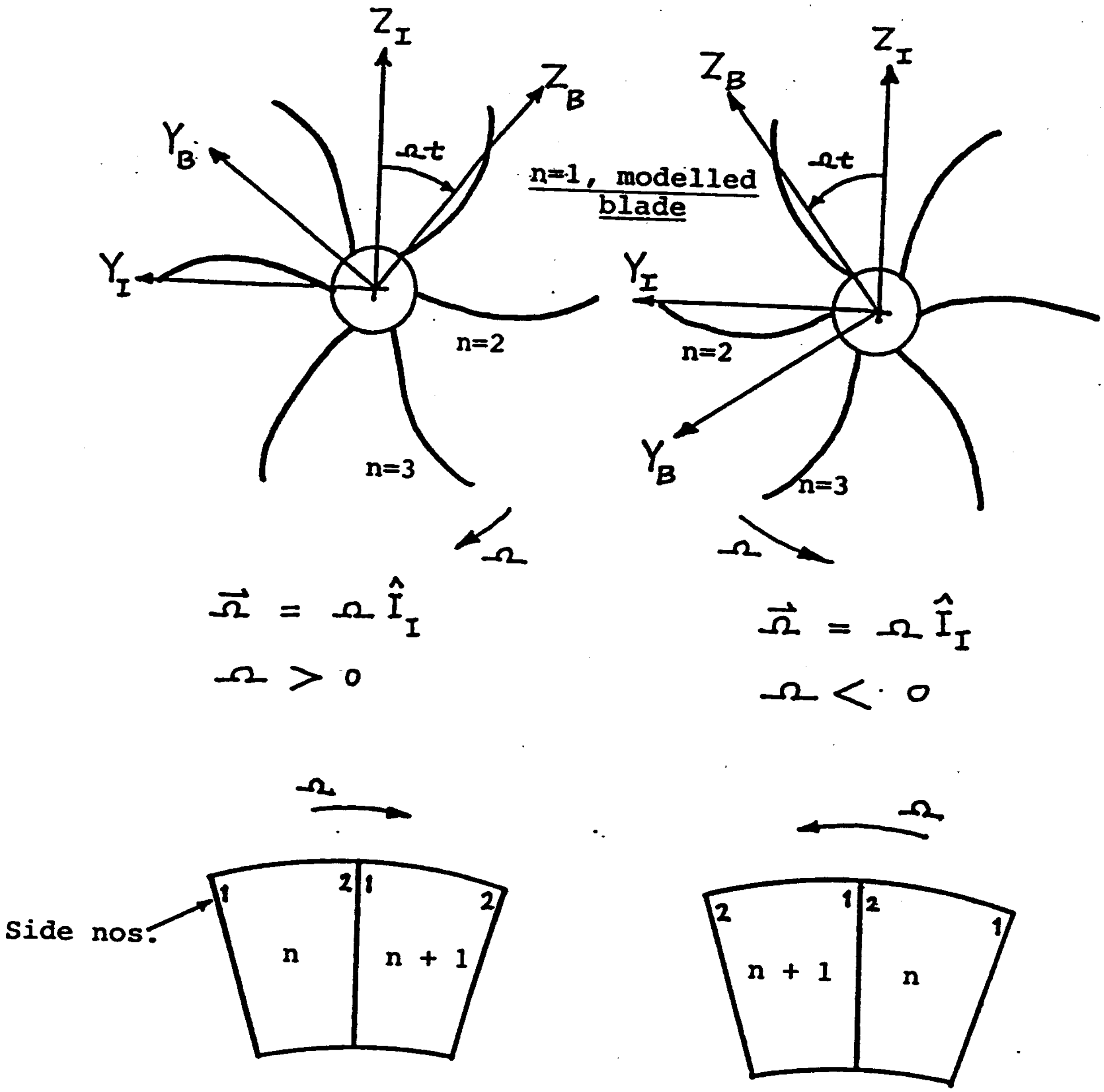
Determination of inter-blade phase angles, excitation reduced frequencies, circumferential harmonic indices, and the relation between the cosine and sine components of applied airloads are described. All cases addressing the turbosystems with flexible or rigid hubs/disks placed in uniform or non-uniform inflow are considered.

A .2 INTER-BLADE PHASE ANGLES

The possible inter-blade angles are determined by factors concerning the nature of the imposed aerodynamic excitation. The following points are noted here to define the inter-blade phase angles:

1. At any given instant of time, equation (7) of Section 2 defines the relative velocity components at the leading edge point of any chord on the reference/modelled/n=1 blade. This blade is also identified in Figure A.1.

2. At the same instant, the relative velocity components at the corresponding point on any other (say, $n_{th.}$) blade can also be obtained from equation (7), Section 2, when



NOTES

1. $\vec{\Omega}$ is the angular velocity of the $X_B Y_B Z_B$ coordinate system w.r.t. the $X_I Y_I Z_I$ coord. system.
2. Modelled sector is always n=1 st. sector.
3. Sector, and side numbers within a sector, increase in the direction of $|\Omega t|$.

Figure A.1 Cyclic Sector and Side Numbering Convention (Ref. 3)

a) T_{ξ}^{BL} is replaced by $T_{\xi}^{BL,n}$ where

$$[T_{\xi}^{BL,n}] = [T_{\bar{\xi}}^{BL}] \begin{bmatrix} 1 & 0 & 0 \\ 0 & \cos\eta & \sin\eta \\ 0 & -\sin\eta & \cos\eta \end{bmatrix}, \qquad \text{(A1)}$$

with

$$\eta = \frac{2\pi}{N}(n-1), \quad n = 1, 2, \ldots, N, \qquad \text{(A2)}$$

and

b) $\{WA\}$Tunnel and $O_B A$ are considered for the n th. blade.

3. Finally, the ratio of the oscillatory part of velocity component $VA_{\bar{y}}$ on the nth. blade to that on the (n+1)th. blade yields the inter-blade phase angle σ as

$$\frac{osc\,(VA)_{\bar{y}},\ n_{th.}\ \text{blade}}{osc\,(VA)_{\bar{y}},\ (n+1)_{th.}\ \text{blade}} = e^{i\sigma}. \qquad \text{(A3)}$$

This definition of σ is consistent with that of Ref. 8 .

The above procedure is used in defining σ in each of the following cases.

A.3 RIGID HUB/DISK, UNIFORM INFLOW

Excitation Reduced Frequency

With the turbosystem axis of rotation misaligned at a small angle with the uniform inflow velocity, the only excitation frequency is given by

$$\omega = \left| \vec{\Omega} \right| , \qquad \text{(A4)}$$

where $\vec{\Omega}$ is the angular velocity of rotation of the turbosystem.

The corresponding reduced frequency for the blade is defined with any of its chords selected as reference:

$$k_{blade} = \frac{\omega \, \ell_{\xi,ref}}{V_{\xi,ref}} , \qquad \text{(A5)}$$

where $\ell_{\xi,ref}$ and $V_{\xi,ref}$ are the semi-chord and cascade relative inflow velocity, respectively, for the reference chord.

Reduced frequencies for other chords are scaled from the above blade value.

Inter-Blade Phase Angle

This is given by

$$\sigma_{blade} = -2\pi / N , \qquad \text{(A6)}$$

with N being the total number of cyclic segments in the structure.

Circumferential Harmonic Index

The only permissible value is 0 , together with the requirement that the degrees of freedom on the segment boundaries be constrained to zero.

Relation Between $\bar{P}^{kc}$ and $\bar{P}^{ks}$

These components of applied airloads are described in in Section 4 . For the rigid hub/disk and uniform inflow case, $\bar{P}^{ks}$ is identically zero, and only $\bar{P}^{kc}$ exists.

A .4 RIGID HUB/DISK, NON-UNIFORM INFLOW

Excitation Reduced Frequency

The possible excitation frequencies are based on the circumferential harmonic contents of the spatially non-uniform inflow, and are given by

$$\omega = p \cdot |\vec{\Omega}| , \tag{A7}$$

where p takes on the positive integer values of the above-mentioned inflow harmonics.

Reduced frequencies are as per equation (A5) with ω's from equation (A7).

Inter-Blade Phase Angle

Permissible inter-blade phase angles are obtained from $\sigma = -p \cdot 2\pi/N$. However, in order to conveniently determine the associated structural circumferential harmonic index, especially in the flexible hub/disk non-uniform inflow case, the inter-blade phase angles are written as follows:

$$\left.\begin{aligned} k_L' &= (N-1)/2 \ , \quad N \text{ odd} \ , \\ &= N/2 \ , \quad N \text{ even} \ . \end{aligned}\right\} \tag{A8}$$

$$\left.\begin{aligned} &\text{For } 0 < p \leq k_L' \ , \quad \sigma = -p \cdot 2\pi/N \ . \\ &\text{For } k_L' + jN < p \leq k_L' + (j+1)N \ , \\ &\qquad \sigma = -p \cdot 2\pi/N + (j+1) \cdot 2\pi \ , \\ &\qquad j = 0, 1, 2, \ldots \ . \end{aligned}\right\} \tag{A9}$$

Circumferential Harmonic Index

The only permissible value is 0, together with the requirement that the degrees of freedom on the segment boundaries be constrained to zero.

Relation Between $\bar{P}^{kc}$ and $\bar{P}^{ks}$

Only $\bar{P}^{kc}$ type loads exist.

A.5 FLEXIBLE HUB/DISK, UNIFORM INFLOW

Excitation Reduced Frequency

The only admissible frequency is

$$\omega = |\vec{\Omega}| \ , \tag{A10}$$

with the reduced frequency given by equation (A5).

Inter-Blade Phase Angle

Only one inter-blade phase angle exists:

$$\sigma = -2\pi/N \quad . \tag{A11}$$

Circumferential Harmonic Index

The only possible index can be written as

$$k = |\sigma| \,/\, (2\pi/N) = 1 \quad . \tag{A12}$$

Relation Between $\bar{P}^{kc}$ and $\bar{P}^{ks}$

These two load components are related as

$$\bar{P}^{ks} = \pm i \, \bar{P}^{kc} \tag{A13}$$

where the + sign applies if $\sigma \lesssim 0$, and the - sign applies otherwise.

A.6 FLEXIBLE HUB/DISK, NON-UNIFORM INFLOW

Excitation Reduced Frequency

The possible excitation frequencies are

$$\omega = p \cdot |\vec{\Omega}| \,, \qquad (A14)$$

where p is a positive integer reflecting the circumferential harmonic contents of the spatially non-uniform inflow.

Reduced frequencies, in turn, are obtained from equation (A5).

<u>Inter-Blade Phase Angle</u>

The permissible values are computed as per equations (A8) and (A9).

<u>Circumferential Harmonic Index</u>

For selected excitation harmonics p, the permissible circumferential harmonics representing the structural motion are given by

$$k = |\sigma| \,/\, (2\pi/N) \,, \qquad (A15)$$

where σ's are from equations (A8) and (A9).

<u>Relation Between $\bar{P}^{kc}$ and $\bar{P}^{ks}$</u>

This is described by equation (A13).

APPENDIX B

COORDINATE SYSTEMS

Due principally to its NASTRAN pre-processing capability, the AIRLOADS program utilizes a number of coordinate systems which provide user convenience in input data preparation. Figure B.1 illustrates these coordinate systems for an advanced turbopropeller with its axis of rotation mounted at an angle with respect to the tunnel mean flow.

Each of these coordinate systems is described as follows:

- $X_T Y_T Z_T$ Tunnel coordinate system

  * This is defined to conveniently specify the velocity components of the spatially non-uniform tunnel free stream. It can be suitably oriented based on the available tunnel data. In the special case of aerodynamic excitation in uniform inflow, the tunnel coordinate system is oriented such that the $X_T Z_T$ plane is parallel to the $X_I Z_I$ plane of the inertial coordinate system as shown in Figure B.2. The origin of the $X_T Y_T Z_T$ system is arbitrarily located. The inclination angle of the turbosystem axis of rotation with respect to the tunnel flow also lies in a plane parallel to $X_I Z_I$ plane. The uniform flow is directed along $+X_T$ axis.

- $X_I Y_I Z_I$ Inertial coordinate system

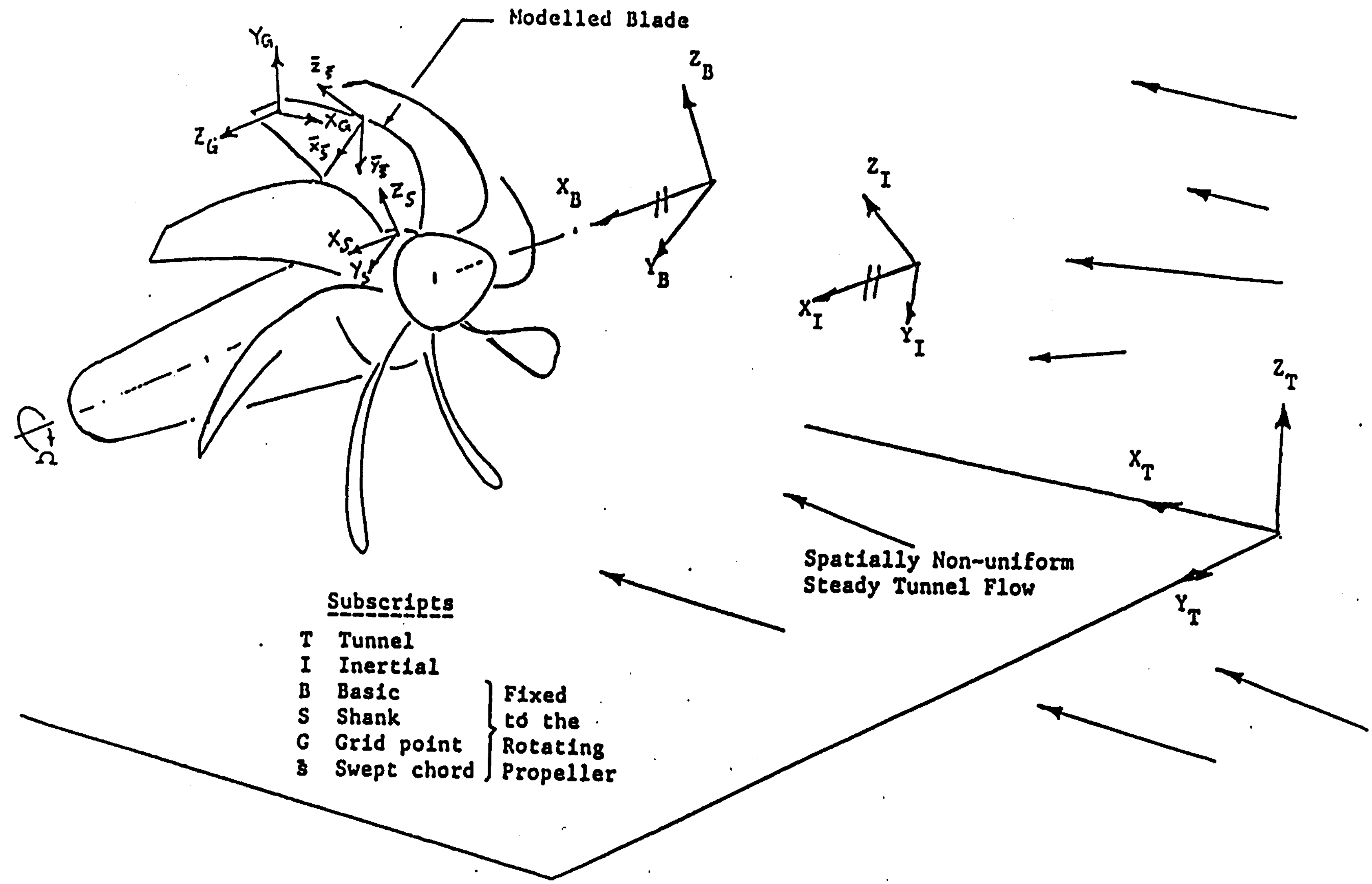


Figure B.1 Coordinate Systems

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NOTES

1. Planes $Z_1Z_2Z_3$ and X_TZ_T need only be parallel to X_IZ_I
2. X_I axis is parallel to Z_3Z_2
3. X_T axis is parallel to Z_1Z_2
4. Uniform Inflow is along $+X_T$

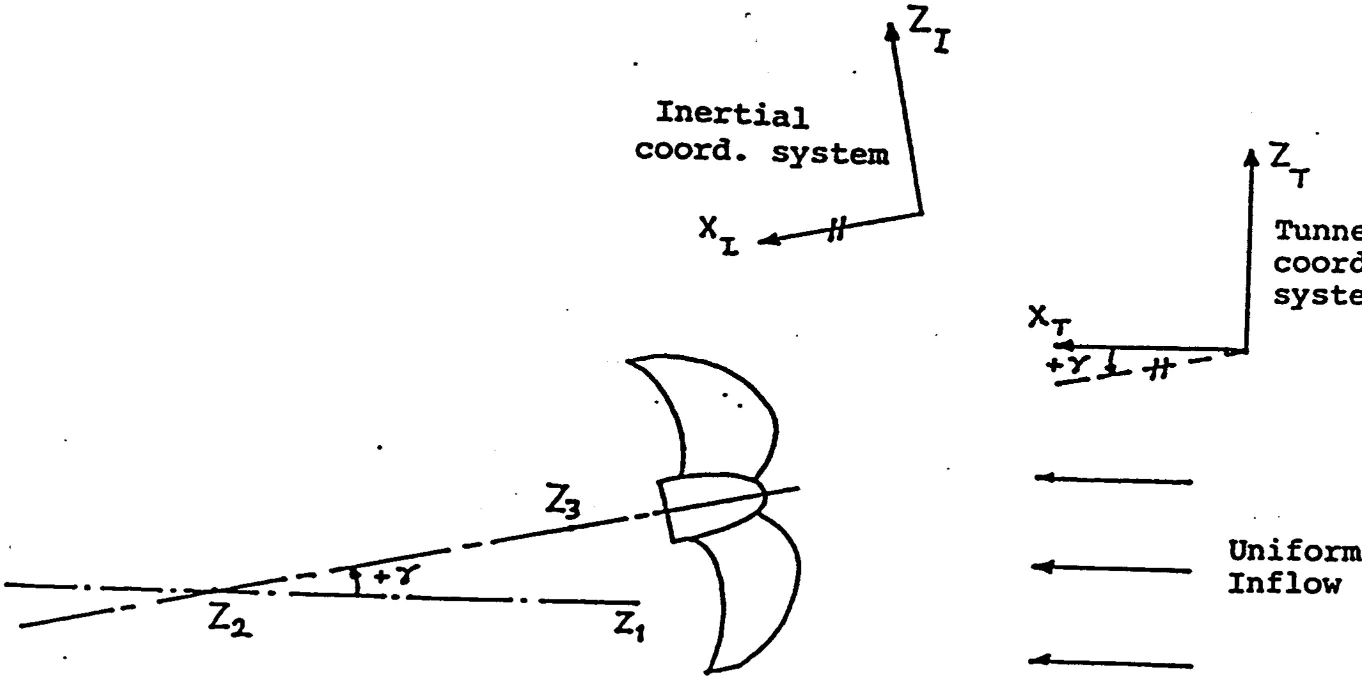

Figure B.2 Turboprop Axis Inclination Angle and Tunnel Coordinate System Orientation in Uniform Inflow Case

* In the present problem, this coordinate system is used to relate the quantities in the tunnel and the basic coordinate systems. The orientation of this coordinate system is completely arbitrary except for the X_I axis to be parallel to, and in the direction of, X_B axis of the basic coordinate system described next. The zero reference for time/phase measurements is defined when the inertial and the basic coordinate systems are parallel.

All of the following NASTRAN coordinate systems are fixed to the rotating turbosystem.

- $X_B Y_B Z_B$ Basic coordinate system

  * This coordinate system has its X_B axis coincident with the turbosystem axis of rotation, and directed aftward. Location of the origin is arbitrary. The $X_B Z_B$ plane contains (approximately) the maximum planform of the modelled blade. The definition of this coordinate system is consistent with the theoretical developments of the 2-d cascade unsteady aerodynamics presently incorporated in the Bladed Disks Computer Program (Ref. 1).

- $X_S Y_S Z_S$ (Blade) shank-fixed coordinate system

  * The principal advantage of this shank-fixed coordinate

system is in modelling changes in the blade setting angles by a simple 3 x 3 transformation matrix relating to the basic coordinate system. Z_S coincides with the blade shank axis. The definition of the coordinate system otherwise is arbitrary.

- $X_G Y_G Z_G$ Grid point location and displacement coordinate systems

  * Any number of such rectangular, cylindrical, or spherical coordinate systems can be completely arbitrarily defined to locate grid points of the NASTRAN model, as well as request output at these grid points. All of the $X_G Y_G Z_G$ coordinate systems used for output requests collectively form the NASTRAN global coordinates system.

- $\bar{x}_{\bar{s}} \bar{y}_{\bar{s}} \bar{z}_{\bar{s}}$ Internally generated coordinate system on swept chord $\bar{s}$

  * This coordinate system is generated within the present Bladed Disks Computer Program, and is used to define flow and motion properties for the unsteady aerodynamic theories on a given swept chord $\bar{s}$. It is located at the blade leading edge with the $\bar{x}_{\bar{s}}$ directed aftward along the chord $\bar{s}$. $\bar{y}_{\bar{s}}$ is defined normal to the blade local mean surface.

REFERENCES

1. Elchuri, V., and Smith G.C.C., "NASTRAN Flutter Analysis of Advanced Turbopropellers," NASA CR 167926, April 1982.

2. Elchuri, V., Gallo, A.M., and Skalski, S.C., "NASTRAN Documentation for Flutter Analysis of Advanced Turbopropellers," NASA CR 167927, April 1982.

3. Elchuri, V., "Modal Forced Vibration Analysis of Aerodynamically Excited Turbosystems," NASA CR 174966, July 1985.

4. Elchuri, V., and Pamidi, P.R., "NASTRAN Supplemental Documentation for Modal Forced Vibration Analysis of Aerodynamically Excited Turbosystems," NASA CR 174967, July 1985.

5. Rao, B.M., and Jones W.P., "Unsteady Airloads for a Cascade of Staggered Blades in Subsonic Flow," 46th Propulsion Energetics Review Meeting, Monterey, California, September 1975.

6. Adamczyk, J.J., and Goldstein, M.E., "Unsteady Flow in a Supersonic Cascade with Subsonic Leading-Edge Locus," AIAA Journal, Vol. 16, No. 12, December 1978, pp. 1248-1254.

7. The NASTRAN User's Manual, NASA SP-222(07), June 1985.

8. Kielb, R.E., and Kaza, K.R.V., "Aeroelastic Characteristics of a Cascade of Mistuned Blades in Subsonic and Supersonic Flows," NASA TM 82631, September 1981.

SYMBOLS

G	Transformation matrix
i	$\sqrt{-1}$
k	Circumferential harmonic index, reduced frequency
l	Semichord
M	Cascade relative inflow Mach number
N	Number of blades on turbosystem
n	n th. cyclic sector
P	Load vector
T	Transformation matrix
t	Time
V	Cascade relative inflow velocity
$\bar{x},\bar{y},\bar{z}$	Chord local coordinates
γ	Inclination angle of turbosystem axis of rotation
Λ	Sweep angle
λ	Stagger angle
ρ	Mass density of flow
σ	Inter-blade phase angle
Ω	Rotational speed
ω	Circular frequency

Subscripts

g	Grid point on chord
$\bar{s}$	Chord $\bar{s}$
$\bar{x},\bar{y},\bar{z}$	Local (chord) coordinate system

Superscripts

B,b	Basic coordinate system
G,g	Global coordinate system
L,l	Local coordinate system
n	n th. cyclic sector
$\bar{s}$	Chord $\bar{s}$
-kc, -ks	Fourier coefficients ('symmetric components')